# A Brief History of the Computer

## by John Dixon

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Published by John Dixon

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# Preface

Ever since the abacus was invented thousands of years ago, the human race has been using devices to help with computation, but it wasn't until the mechanical calculator was invented by Wilhelm Schickard in 1623 that the era of the computer truly began. His invention – the calculating clock – used cogs and gears and was a long way away from where we are today with our mobile phones, tablets and laptops, but it did signify a significant development in the use of calculating devices, and mechanical calculators were used well into the 20th century. In fact, the slide rule, which is a type of mechanical calculator, is still used today by some engineers, even though it was invented way back in the 1620s by William Oughtred.

The invention of the punched card in 1801 was another significant milestone in the history of the computer. In 1801, Joseph-Marie Jacquard developed a loom in which punched cards controlled the pattern being woven. The series of cards could be changed without changing the mechanical design of the loom ... this was a landmark point in programmability.

The defining feature of a computer is the ability to program it, and programmable machines gradually became more widespread from about 1835 onwards. A program enables a computer to emulate different calculating machines by using different stored sequences of instructions. In 1837, Charles Babbage described his Analytical Engine, which was a general purpose programmable computer that used punched cards for input and a steam engine for power. Babbage never built his Analytical Engine, but a model of part of it is on display at the Science Museum in London, UK.

Electronic calculators didn't appear until the 1960s, with the Sumlock Comptometer Anita C/VIII quite possibly being the first. Its price tag though was a hefty $2200. Electrical digital computers themselves were invented in the 1940s, with the onset of the Second World War causing great advances to be made in computer design and development. Electronic circuits, relays, capacitors and vacuum tubes replaced their mechanical equivalents, and digital calculations replaced analog ones.

The next major step in the history of the computer was the invention of the transistor in 1947, which replaced the fragile and power-hungry valves with a much smaller and reliable component. This was the beginning of miniaturization. Through the 1950s and 60s computers became more widespread, and in 1959 IBM started selling the transistor-based IBM 1401. In total, 12000 were shipped, making it the most successful computer of that period.

The explosion in computers really began with the invention of the integrated circuit (or microchip), which led to the invention of the microprocessor at Intel. The microprocessor led, in turn, to the development of the microcomputer. Microcomputers were affordable to small businesses and individuals alike, and continued the unstoppable technological march that has brought us to where we are today.

# About this Book

This book will take you on a nostalgic journey as we look back at the people, computers, programming languages and games that have forged the history of the computer.

## The YouTube Channel

Any videos that accompany this book are available on our YouTube channel, which you can find here:

https://www.youtube.com/channel/UChoBHeUk6tc6Si2hrdOYJOw

## Who this Book is for

This book is for anyone who is interested in learning about the history of the computer. The book isn't exhaustive, but it should give you a taster that will hopefully encourage you to carry out more research on the history of the computer should you wish to do so.

## Quick Start Workbooks

You can find information about other books written by John Dixon at the Quick Start Workbook website:

http://www.quickstartworkbook.com

## How this Book is Organised

Each chapter in this book looks at a major area of the history of the computer, beginning the computer itself, we then move on to look at programming languages, the microprocessor, operating systems, and computer games.

### Chapter 1 - The Computer

Computing hardware has been an essential component of the process of calculation and data storage since it became useful for numerical values to be processed and shared. The earliest computing hardware was probably some form of tally stick. In this chapter we'll take a look at some of the most significant advances that have been made in the world of computing over the past few hundred years.

## Chapter 2 - Programming Languages

This article discusses the major developments in the history of programming languages.

The first programming languages predate the modern computer. Herman Hollerith realized that he could encode information on punch cards when he observed that railroad train conductors would encode the appearance of the ticket holders on the train tickets using the position of punched holes on the tickets.

## Chapter 3 – The Microprocessor

A microprocessor (sometimes abbreviated µP) is a digital electronic component with transistors on a single semiconductor integrated circuit (IC). One or more microprocessors typically serve as a central processing unit (CPU) in a computer system or handheld device. Microprocessors made possible the advent of the microcomputer.

## Chapter 4 – Operating Systems

A computer’s operating system (OS) provides a set of functions needed and used by most applications, and provides the necessary linkages to control a computer's hardware. On the first computers, without an operating system, each program would need its own drivers for the video card, memory card, and other peripherals. The evolution of computer applications and their complexity led to the OS necessities.

## Chapter 5 – Computer Games

Although the history of computer and video games spans five decades, computer and video games themselves did not become part of the popular culture until the late 1970s. Over the past three or four decades, video games have become extremely popular, either in the form of hand held consoles, or with games that run on computers or attached to TVs. The range of games available is also immense, with action, strategy, adventure, and sports games being very popular. In this chapter we will look at how computer and other video games have evolved since the 1960s.

# About Me

My name is John Dixon and I have been working as a Technical Author for the past 30 years. During this time I have written numerous manuals about software applications, operating systems, and computer hardware.

I love writing and I enjoy designing and developing websites, which is something I have been doing since 1997 when I produced my first website whilst working at Hewlett-Packard in Grenoble, France. Since then I have designed and built sites for large companies such as IBM, as well as many small companies.

I began my working career as an engineering apprentice in 1979. This almost seems like the dark ages now, and I remember that at my first company we had one desktop computer for the whole firm ... and there were over 1100 of us! Apart from using a mini computer at college, my first experience of computing wasn't until the mid-eighties when I was working at an electronics company, which incidentally is where I began my technical authoring career. I don't think anyone then could have imagined where the computer industry would be today.

My LinkedIn address is shown below. I'd be pleased to hear from you if you have any comments on this book – good or bad – or if you just want to connect with me.

*uk.linkedin.com/pub/john-dixon/1/648/a52*

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# Chapter 1

## The Computer

Computing hardware has been an essential component of the process of calculation and data storage since it became useful for numerical values to be processed and shared. The earliest computing hardware was probably some form of tally stick; later recording devices include the Phoenician clay shapes which represented quantities or 'counts' of items, probably livestock or grains, in containers. These seem to have been used by the merchants, accountants, and government officials of the time.

Devices to aid computation have evolved from simple recording and counting devices through the abacus, the slide rule, early electronic computers to the sophisticated mobile computing devices we have today. However, it's interesting that even today, an experienced abacus user using a device designed hundreds of years ago can sometimes complete basic calculations more quickly than an unskilled person using an electronic calculator - though for more complex calculations, computers can easily out-perform even the most skilled human.

### In the Beginning...

Humanity has used devices to aid in computation for millennia. One example is a device for establishing equality by weight: the classic scales, later used to symbolize equality in justice. Another is simple enumeration: the checkered cloths of the counting houses served as simple data structures for enumerating stacks of coins, by weight. A more arithmetic-oriented machine is the abacus. One of the earliest machines of this type was the Chinese abacus, which was invented about 5000 years ago.

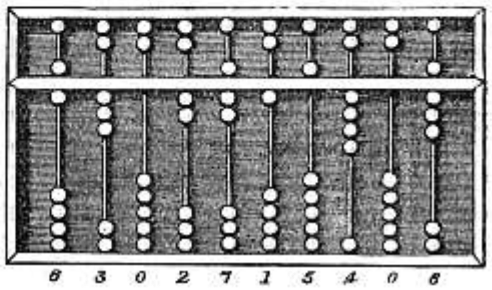

*Figure 1-1 - The Chinese Abacus*

## The First Mechanical Calculators

In 1623 Wilhelm Schickard built the first mechanical calculator and thus became the father of the computing era.

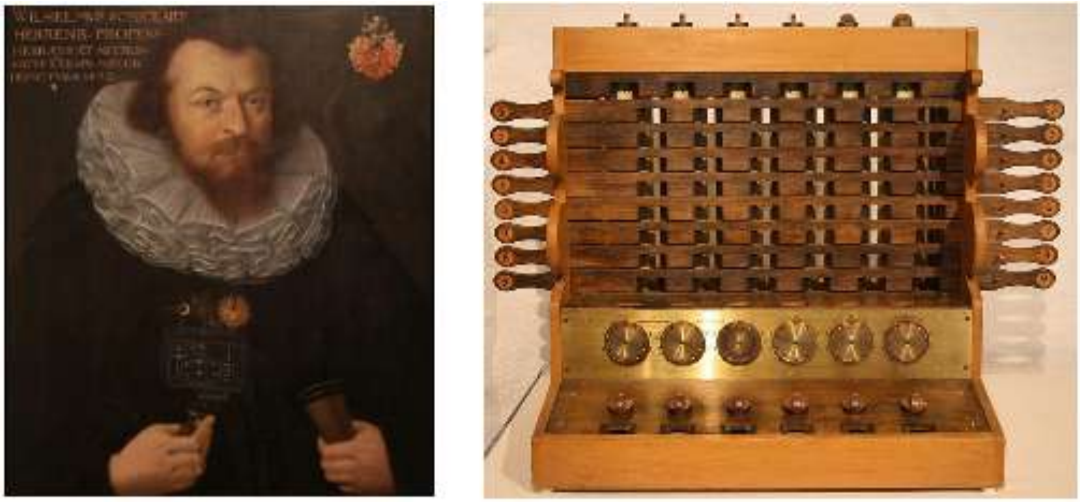

*Figure 1-2 – Wilhelm Schickard and a replica of his calculating machine*

Since his machine used techniques such as cogs and gears that were first developed for clocks, it was also called a 'calculating clock'. It was put to practical use by his friend, the astronomer Johannes Kepler.

Machines by Blaise Pascal (the Pascaline, 1642) and Gottfried Wilhelm von Leibniz (1671) followed. Around 1820, Charles Xavier Thomas created the first successful, mass-produced mechanical calculator, the Thomas Arithmometer, that could add, subtract, multiply, and divide. It was mainly based on Leibniz's work. Mechanical calculators, like the base-ten addiator, the comptometer, the Monroe, the Curta and the Addo-X remained in use until the 1970s.

Leibniz also described the binary numeral system, which is a central ingredient of all modern computers. However, up to the 1940s, many subsequent designs (including Charles Babbage's machines of the 1800s and even ENIAC of 1945) were based on the harder-to-implement decimal system.

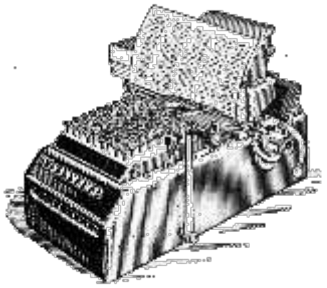

*Figure 1-3 - A mechanical calculator from 1914*

## Napier’s Bones

John Napier (1550-1617) - a Scottish mathematician, physicist, and astronomer - noted that multiplication and division of numbers can be performed by addition and subtraction, respectively, of logarithms of those numbers. While producing the first logarithmic tables Napier needed to perform many multiplications, and it was at this point that he designed Napier's bones.

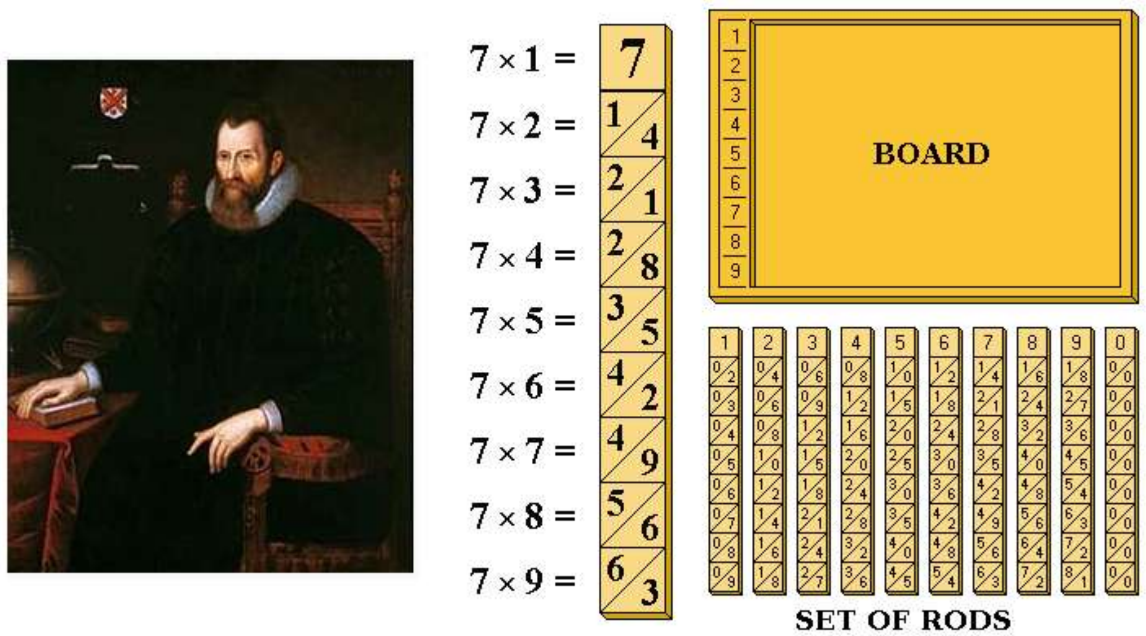

*Figure 1-4 – John Napier and Napier’s Bones*

Napier’s bones provide a mechanical method for performing multiplication and division, based upon manipulation of rods with printed digits. They became a very popular calculating device because most people lacked these mathematical skills.

## The Slide Rule

The slide rule, invented by William Oughtred in the 1620s, allowed multiplication and division operations to be carried significantly faster than was previously possible. Slide rules were used by generations of engineers and other mathematically inclined professional workers until the invention of the pocket calculator. The engineers in the Apollo program to send a man to the moon made many of their calculations on slide rules, which were accurate to 3 or 4 significant figures.

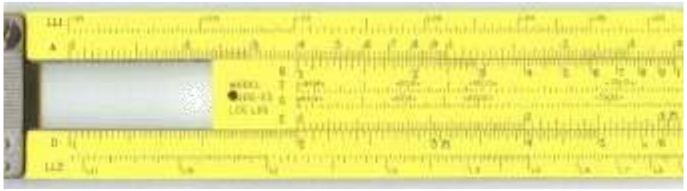

*Figure 1-5 - The slide rule, a basic mechanical calculator, facilitates multiplication and division*

## Punched Card Technology (1801)

In 1801, Joseph-Marie Jacquard developed a loom in which the pattern being woven was controlled by punched cards. The series of cards could be changed without changing the mechanical design of the loom. This was a landmark point in programmability.

In 1833, Charles Babbage moved on from developing his difference engine to developing a more complete design, the analytical engine which would draw directly on Jacquard's punch cards for its programming.

In 1890, the United States Census Bureau used punch cards and sorting machines designed by Herman Hollerith to handle the flood of data from the decennial census mandated by the Constitution. Hollerith's company eventually became the core of IBM. IBM developed punch card technology into a powerful tool for business data processing and produced an extensive line of specialized unit record equipment. By 1950 the IBM card had become ubiquitous in industry and government. The warning printed on most cards, "Do not fold, spindle or mutilate", became a motto for the post-World War II era.

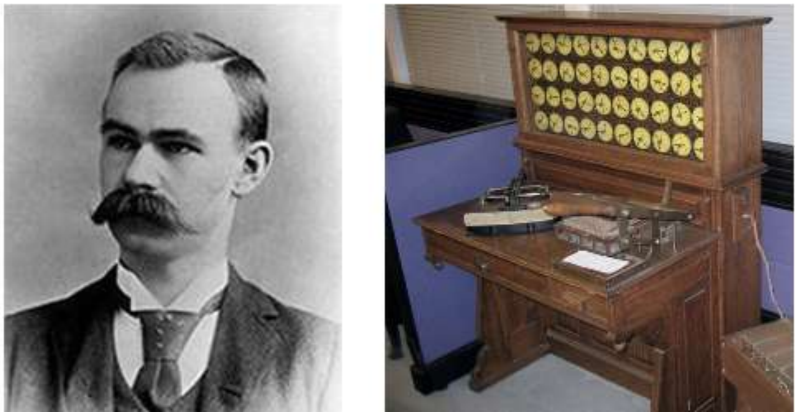

*Figure 1-6 - Herman Hollerith invented a tabulating machine using punch cards in the 1880s*

The tabulating machine was an electromechanical machine designed to assist in summarizing information and, later, accounting.

Leslie Comrie's articles on punch card methods and W.J. Eckert's publication of Punched Card Methods in Scientific Computation in 1940, described techniques which were sufficiently advanced to solve differential equations, perform multiplication and division using floating point representations, all on punched cards and plug-boards similar to those used by telephone operators. The Thomas J. Watson Astronomical Computing Bureau, Columbia University performed astronomical calculations representing the state of the art in computing.

In many computer installations, punched cards were used until (and after) the end of the 1970s. For example, science and engineering students at many universities around the world would submit their programming assignments to the local computer centre in the form of a stack of cards, one card per program line, and then had to wait for the program to be queued for processing, compiled, and executed. In due course a printout of any results, marked with the submitter's identification, would be placed in an output tray outside the computer center. In many cases these results would comprise solely a printout of error messages regarding program syntax etc., necessitating another edit-compile-run cycle.

Punched cards are still used and manufactured in the current century, and their distinctive dimensions (and 80-column capacity) can still be recognised in forms, records, and programs around the world.

## The First Programmable Machines (1835-1900)

The defining feature of a "universal computer" is programmability, which allows the computer to emulate any other calculating machine by changing a stored sequence of instructions.

In 1837, Charles Babbage described his analytical engine. It was the plan of a general-purpose programmable computer, employing punch cards for input and a steam engine for power. One crucial invention was to use gears for the function served by the beads of an abacus. In a real sense, computers all contain automatic abacuses (technically called the ALU or floating-point unit).

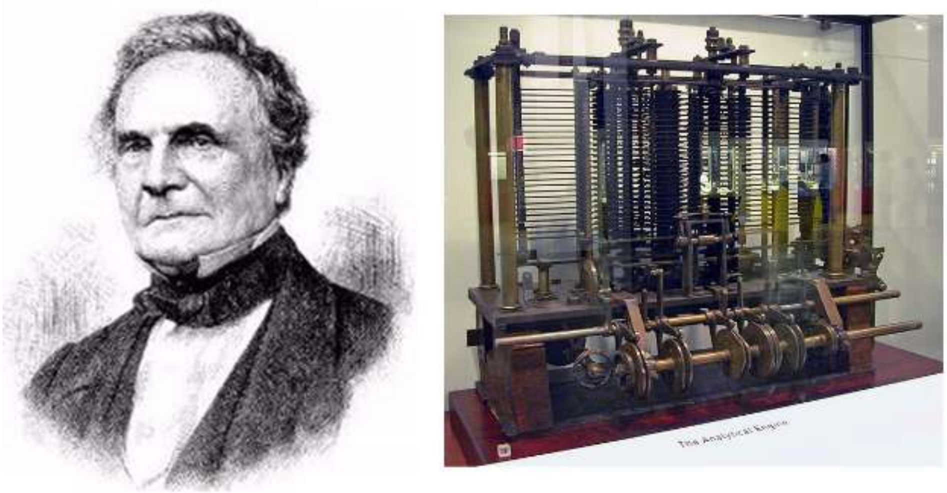

*Figure 1-7 - Charles Babbage and a model of part of the Analytical Engine, as displayed at the Science Museum (London)*

Babbage's initial idea was to use punch-cards to control a machine that could calculate and print logarithmic tables with huge precision (a specific purpose machine). His idea soon developed into a general-purpose programmable computer, his analytical engine.

While his design was sound and the plans were probably correct, or at least debuggable, the project was slowed by various problems. Babbage was a difficult man to work with and argued with anyone who didn't respect his ideas. All the parts for his machine had to be made by hand and small errors in each item were summed up as huge discrepancies in a machine with thousands of parts. The project dissolved over disputes with the artisan who built parts and was ended with the depletion of government funding.

Ada Lovelace, Lord Byron's daughter, translated and added notes to the "Sketch of the Analytical Engine" by Federico Luigi, Conte Menabrea. She has become closely associated with Babbage. Some claim she is the world's first computer programmer, however this claim and the value of her other contributions are disputed by many.

*Figure 1-8 - Augusta Ada King, Countess of Lovelace*

A reconstruction of the Difference Engine II, an earlier, more limited design, has been operational since 1991 at the London Science Museum. With a few trivial changes, it works as Babbage designed it and shows that Babbage was right in theory.

The museum used computer-operated machine tools to construct the necessary parts, following tolerances which a machinist of the period would have been able to achieve. Some feel that the technology of the time was unable to produce parts of sufficient precision, though this appears to be false.

The failure of Babbage to complete the engine can be chiefly attributed to difficulties not only related to politics, but also his desire to develop an increasingly sophisticated computer. Personal finance failing and an overly ambitious attitude for his time, eventually led to his failure. Today, many in the computer field term this sort of obsession creeping featuritis. Babbage may have been able to finance this project better if he had been able to work with people better, and with better leadership and management skills the government may well have been more inclined to continue their financial contributions.

Following in the footsteps of Babbage, although unaware of his earlier work, was Percy Ludgate, an accountant from Dublin, Ireland. He independently designed a programmable mechanical computer, which he described in a work that was published in 1909.

## Desktop Calculators (1930s-1960s)

By the 1900s, earlier mechanical calculators, cash registers, accounting machines, and so on were redesigned to use electric motors, with gear position as the representation for the state of a variable. Companies like Friden, Marchant and Monroe made desktop mechanical calculators from the 1930s that could add, subtract, multiply and divide. The word "computer" was a job title assigned to people who used these calculators to perform mathematical calculations. During the Manhattan project, future Nobel laureate Richard Feynman was the supervisor of the roomful of human computers, many of them women mathematicians, who understood the differential equations which were being solved for the war effort. Even the renowned Stanislaw Marcin Ulam was pressed into service to translate the mathematics into computable approximations for the hydrogen bomb, after the war.

In 1948, the Curta was introduced. This was a small, portable, mechanical calculator that was about the size of a pepper grinder. Over time, during the 1950s and 1960s, a variety of different brands of mechanical calculator appeared on the market.

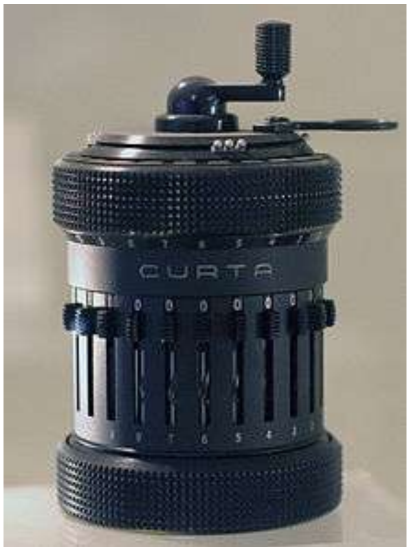

*Figure 1-9 – Curta Mechanical Calculator*

The first desktop electronic calculator was probably Sumlock Comptometer's 1961 Anita C/VIII, which used a Nixie tube display and 177 subminiature thyratron tubes. In June 1963, Friden introduced the four-function EC-130. It had an all-transistor design, 13-digit capacity on a 5-inch CRT, and introduced reverse Polish notation (RPN) to the calculator market at a price of $2200.

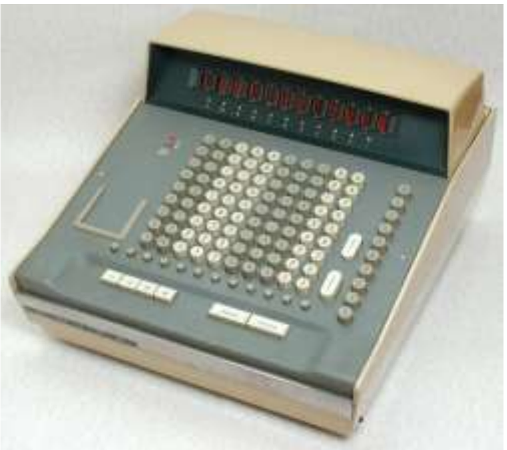

*Figure 1-10 - Sumlock Comptometer's 1961 Anita C/VIII Electronic Calculator*

The acronym 'ANITA' was officially proclaimed to be derived from, variously, **A** **N**ew **I**nspiration **T**o **A**rithmetic, or **A** **N**ew **I**nspiration **T**o **A**ccounting, though there have been rumours that this was also the name of the designer's wife.

The model EC-132 added square root and reciprocal functions. In 1965, Wang Laboratories produced the LOCI-2, a 10-digit transistorized desktop calculator that used a Nixie tube display and could compute logarithms.

With development of the integrated circuits and microprocessors, the expensive, large calculators were replaced with smaller electronic devices.

## The Arrival of the Electrical Digital Computer (1940s)

The era of modern computing began with a flurry of development before and during World War II, as electronic circuits, relays, capacitors and vacuum tubes replaced mechanical equivalents and digital calculations replaced analog calculations. The computers designed and constructed during this period have sometimes been called 'first generation' computers.

First generation computers such as the Atanasoff-Berry Computer, Z3 and Colossus were built by hand, using circuits containing relays or vacuum valves (tubes), and often used punched cards or punched paper tape for input and as the main (non-volatile) storage medium. Temporary, or working storage, was provided by acoustic delay lines (which use the propagation time of sound in a medium such as wire to store data) or by Williams tubes (which use the ability of a television picture tube to store and retrieve data). By 1954, magnetic core memory was rapidly displacing most other forms of temporary storage, and dominated the field through the mid-1970s.

In this era, a number of different machines were produced with steadily advancing capabilities. At the beginning of this period, nothing remotely resembling a modern computer existed, except in the long-lost plans of Charles Babbage and the mathematical musings of Alan Turing and others. At the end of the era, devices like the EDSAC had been built, and are universally agreed to be digital computers.

Alan Turing's 1936 paper has proved enormously influential in computing and computer science in two ways. Its main purpose was an elegant proof that there were problems (namely the halting problem) that could not be solved by a mechanical process (a computer). In doing so, however, Turing provided a definition of what a universal computer is: a construct called the Turing machine, a purely theoretical device invented to formalize the notion of algorithm execution, replacing Kurt Gödel's more cumbersome universal language based on arithmetic. Modern computers are Turing-complete (i.e., equivalent algorithm execution capability to a universal Turing machine), except for their finite memory. This limited type of Turing completeness is sometimes viewed as a threshold capability separating general-purpose computers from their special-purpose predecessors.

> ***Turing-Complete (taken from Wikipedia)***
>
> *Turing completeness, named after Alan Turing, is significant in that every plausible design for a computing device so far advanced can be emulated by a universal Turing machine — an observation that has become known as the Church-Turing thesis. Thus, a machine that can act as a universal Turing machine can, in principle, perform any calculation that any other programmable computer is capable of. However, this has nothing to do with the effort required to write a program for the machine, the time it may take for the machine to perform the calculation, or any abilities the machine may possess that are unrelated to computation.*
>
> *While truly Turing-complete machines are very likely physically impossible, as they require unlimited storage, Turing completeness is often loosely attributed to physical machines or programming languages that would be universal if they had unlimited storage. All modern computers are Turing-complete in this sense.*

However, theoretical Turing-completeness is a long way from a practical universal computing device. To be a practical general-purpose computer, there must be some convenient way to input new programs into the computer, such as punched tape. For full versatility, the Von Neumann architecture uses the same memory both to store programs and data; virtually all contemporary computers use this architecture (or some variant). Finally, while it is theoretically possible to implement a full computer entirely mechanically (as Babbage's design showed), electronics made possible the speed and later the miniaturization that characterises modern computers.

There were three parallel streams of computer development in the World War II era, and two were either largely ignored or were deliberately kept secret. The first was the German work of

Konrad Zuse. The second was the secret development of the Colossus computer in the UK. Neither of these had much influence on the various computing projects in the United States. After the war, British and American computing researchers cooperated on some of the most important steps towards a practical computing device.

## American Developments

In 1937, Claude Shannon produced his master's thesis at MIT that implemented Boolean algebra using electronic relays and switches for the first time in history. Entitled A Symbolic Analysis of Relay and Switching Circuits, Shannon's thesis essentially founded practical digital circuit design.

In November of 1937, George Stibitz, then working at Bell Labs, completed a relay-based computer he dubbed the "Model K" (for "kitchen", where he had assembled it), which calculated using binary addition. Bell Labs thus authorized a full research program in late 1938 with Stibitz at the helm. Their Complex Number Calculator, completed January 8, 1940, was able to calculate complex numbers. In a demonstration to the American Mathematical Society conference at Dartmouth College on September 11, 1940, Stibitz was able to send the Complex Number Calculator remote commands over telephone lines by a teletype. It was the first computing machine ever used remotely over a phone line. Some participants of the conference who witnessed the demonstration were John Von Neumann, John Mauchly, and Norbert Wiener, who wrote about it in his memoirs.

In 1938 John Vincent Atanasoff and Clifford E. Berry of Iowa State University developed the Atanasoff-Berry Computer (ABC), a special purpose electronic computer for solving systems of linear equations. The design used over 300 vacuum tubes for high speed and employed capacitors fixed in a mechanically rotating drum for memory. Though the ABC machine was not programmable, it was the first modern computer in several other respects, including the first to use binary math and electronic circuits. ENIAC (Electronic Numerical Integrator and Computer) co-inventor John Mauchly visited the ABC while it was still under construction in June 1941, and its influence over the design of the ENIAC is a matter of contention among computer historians. The ABC was largely forgotten until it became the focus of the lawsuit Honeywell v. Sperry Rand, which invalidated the ENIAC patent.

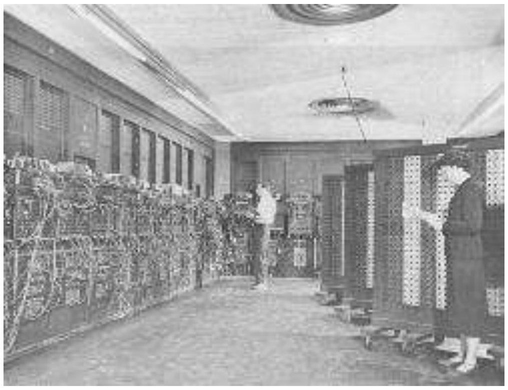

*Figure 1-11 - ENIAC performed ballistics trajectory calculations with 160 kW of power. Source: U.S. Army Photo, from K. Kempf.*

In 1939, development began at IBM's Endicott laboratories on the Harvard Mark I. Known officially as the Automatic Sequence Controlled Calculator, the Mark I was a general purpose electro-mechanical computer built with IBM financing and with assistance from some IBM personnel under the direction of Harvard mathematician Howard Aiken. Its design was influenced by the Analytical Engine. It was a decimal machine which used storage wheels and rotary switches in addition to electromagnetic relays. It was programmable by punched paper tape, and contained several calculators working in parallel. Later models contained several paper tape readers and the machine could switch between readers based on a condition. Nevertheless, this does not quite make the machine Turing-complete. The Mark I was moved to Harvard University to begin operation in May 1944.

The US-built ENIAC, often called the first electronic general-purpose computer, publicly validated the use of electronics for large-scale computing. This was crucial for the development of modern computing, initially because of the enormous speed advantage, but ultimately because of the potential for miniaturization. Built under the direction of John Mauchly and J. Presper Eckert, it was 1,000 times faster than its contemporaries. ENIAC's development and construction lasted from 1941 to full operation at the end of 1945. When its design was proposed, many researchers believed that the thousands of delicate valves (i.e. vacuum tubes) would burn out often enough that the ENIAC would be so frequently down for repairs as to be useless. It was, however, capable of up to thousands of operations per second for hours at a time between valve failures.

ENIAC was unambiguously a Turing-complete device. To 'program' ENIAC, however, meant to rewire it--some say this does not even qualify as programming, otherwise any type of rebuilding some limited computer might be viewed as programming. At the time, however, unaided calculation was seen as enough of a triumph to view the solution of a single problem as the object of a program. (Improvements completed in 1948 made it possible to execute stored programs that were set in function table memory, which made programming less of a one-off effort and more systematic.)

Jon von Neumann, based on ideas developed by Eckhart and Mauchly after recognising the limitations of ENIAC, wrote a widely-circulated report describing a computer design (the EDVAC design) in which the programs and working data were both stored in a single, unified store. This basic design, which became known as the von Neumann architecture, would serve as the basis for the development of the first really flexible, general-purpose digital computers.

## Colossus

During World War II, the British at Bletchley Park achieved a number of successes at breaking encrypted German military communications. The German encryption machine, Enigma, was attacked with the help of electro-mechanical machines called bombes. The bombe, designed by Alan Turing and Gordon Welchman, after Polish bomba, ruled out possible Enigma settings by performing chains of logical deductions implemented electrically. Most possibilities led to a contradiction, and the few remaining could be tested by hand.

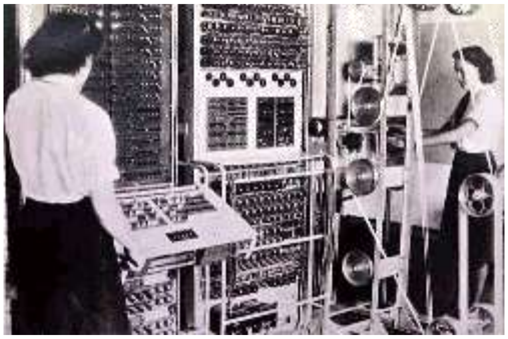

*Figure 1-12 - Colossus was used to break German ciphers during World War II*

The Germans also developed a series of teleprinter encryption systems, quite different from Enigma. The Lorenz SZ 40/42 machine was used for high-level army communications, termed "Tunny" by the British. The first intercepts of Lorenz messages began in 1941. As part of an attack on Tunny, Professor Max Newman and his colleagues helped specify the Colossus. The Mk I Colossus was built in 11 months by Tommy Flowers and his colleagues at the Post Office Research Station at Dollis Hill in London and then shipped to Bletchley Park.

Colossus was the first totally electronic computing device. The Colossus used a large number of valves (vacuum tubes). It had paper-tape input and was capable of being configured to perform a variety of boolean logical operations on its data, but it was not Turing-complete. Nine Mk II Colossi were built (The Mk I was converted to a Mk II making ten machines in total). Details of their existence, design, and use were kept secret well into the 1970s. Winston Churchill personally issued an order for their destruction into pieces no larger than a man's hand. Due to this secrecy the Colossi were not included in many histories of computing. A reconstructed copy of one of the Colossus machines is now on display at Bletchley Park.

## Konrad Zuse's Z-series

Working in isolation in Nazi Germany, Konrad Zuse started construction in 1936 of his first Z-series calculators featuring memory and (initially limited) programmability. Zuse's purely mechanical, but already binary Z1, finished in 1938, never worked reliably due to problems with the precision of parts.

Zuse's subsequent machine, the Z3, was finished in 1941. It was based on telephone relays and did work satisfactorily. The Z3 thus became the first functional program-controlled computer. In many ways it was quite similar to modern machines, pioneering numerous advances, such as floating point numbers. Replacement of the hard-to-implement decimal system (used in Charles Babbage's earlier design) by the simpler binary system meant that Zuse's machines were easier to build and potentially more reliable, given the technologies available at that time. This is sometimes viewed as the main reason why Zuse succeeded where Babbage failed.

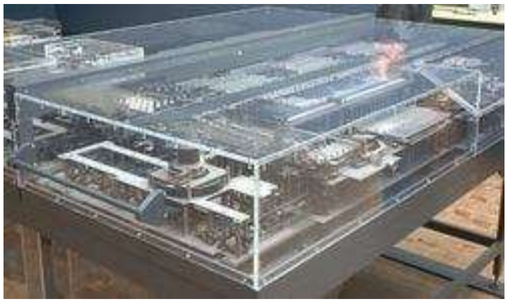

*Figure 1-13 - A reproduction of Zuse's Z1 computer*

Programs were fed into the Z3 on punched films. Conditional jumps were missing, but since the 1990s it has been proved theoretically that the Z3 was still a universal computer (ignoring its physical storage size limitations). In two 1937 patents, Konrad Zuse also anticipated that machine instructions could be stored in the same storage used for data - the key insight of what became known as the Von Neumann architecture and was first implemented in the later British EDSAC design (1949). Zuse also claimed to have designed the first higher-level programming language - Plankalkül - in 1945, although it was never formally published until 1971, and was implemented for the first time in 2000 by the Free University of Berlin -- five years after Zuse died.

Zuse suffered setbacks during World War II when some of his machines were destroyed in the course of Allied bombing campaigns. Apparently his work remained largely unknown to engineers in the UK and US until much later, although at least IBM was aware of it as it financed his post-war startup company in 1946 in return for an option on Zuse's patents.

## First Generation Von Neumann Machines

The first working von Neumann machine was the Manchester "Baby" or Small-Scale Experimental Machine, built at the University of Manchester in 1948. It was followed in 1949 by the Manchester Mark I computer, which functioned as a complete system using the Williams tube for memory, and also introduced index registers. The other contender for the title "first digital stored program computer" was EDSAC (Electronic Delay Storage Automatic Calculator), designed and constructed at the University of Cambridge. Operational less than one year after the Manchester "Baby", it was capable of tackling real problems. EDSAC was actually inspired by plans for EDVAC (Electronic Discrete Variable Automatic Computer), the successor of ENIAC; these plans were already in place by the time the ENIAC was successfully operational. Unlike the ENIAC, which used parallel processing, EDVAC used a single processing unit. This design was simpler and was the first to be implemented in each succeeding wave of miniaturization, and increased reliability. Some view Manchester Mark I / EDSAC / EDVAC as the "Eves" from which nearly all current computers derive their architecture.

The first universal programmable computer in continental Europe was created by a team of scientists under direction of Sergei Alekseyevich Lebedev from Kiev Institute of Electrotechnology, Soviet Union (now Ukraine). The computer MESM (possibly standing for Small Electronic Calculating Machine) became operational in 1950. It had about 6,000 vacuum tubes and consumed 25 kW of power. It could perform approximately 3,000 operations per second. Another early machine was CSIRAC, an Australian design that ran its first test program in 1949.

In October 1947, the directors of J. Lyons & Company, a British catering company famous for its teashops but with strong interests in new office management techniques, decided to take an active role in promoting the commercial development of computers. By 1951 the LEO I computer was operational and ran the world's first regular routine office computer job.

Manchester University's machine became the prototype for the Ferranti Mark I. The first Ferranti Mark I machine was delivered to the University in February, 1951 and at least nine others were sold between 1951 and 1957.

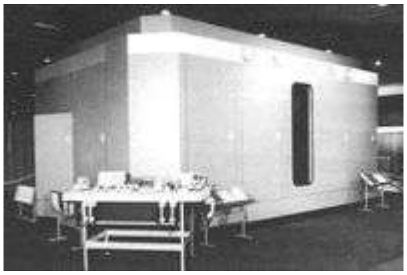

*Figure 1-14 - UNIVAC I, the first commercial electronic computer, achieved 1900 operations per second in a smaller and more efficient package than ENIAC*

In June 1951, the UNIVAC I (Universal Automatic Computer) was delivered to the U.S. Census Bureau. Although manufactured by Remington Rand, the machine often was mistakenly referred to as the "IBM UNIVAC". Remington Rand eventually sold 46 machines at more than $1 million each. UNIVAC was the first 'mass produced' computer; all predecessors had been 'one-off' units. It used 5,200 vacuum tubes and consumed 125 kW of power. It used a mercury delay line capable of storing 1,000 words of 11 decimal digits plus sign (72-bit words) for memory. Unlike earlier machines it did not use a punch card system but a metal tape input.

In November 1951, the J. Lyons company began weekly operation of a bakery valuations job on the LEO (Lyons Electronic Office). This was the first business application to go live on a stored program computer.

In 1952, IBM publicly announced the IBM 701 Electronic Data Processing Machine, the first in its successful 700/7000 series and its first IBM mainframe computer. The IBM 704, introduced in 1954, used magnetic core memory, which became the standard for large machines. Fortran, which was the first high-level general purpose programming language to be implemented, was also being developed at IBM for the 704 during 1955 and 1956 and released in early 1957.

(Konrad Zuse's 1945 design of the high-level language Plankalkül was not implemented at that time.)

IBM introduced a smaller, more affordable computer in 1954 that proved very popular. The IBM 650 weighed over 900 kg, the attached power supply weighed around 1350 kg and both were held in separate cabinets of roughly 1.5 meters by 0.9 meters by 1.8 meters. It cost $500,000 or could be leased for $3,500 a month. Its drum memory was originally only 2000 ten-digit words, and required arcane programming for efficient computing. Memory limitations such as this were to dominate programming for decades afterward, until the evolution of a programming model which was more sympathetic to software development.

In 1955, Maurice Wilkes invented microprogramming, which was later widely used in the CPUs and floating-point units of mainframe and other computers, such as the IBM 360 series. Microprogramming allows the base instruction set to be defined or extended by built-in programs (now sometimes called firmware, microcode, or millicode).

*Figure 1-15 - Maurice Wilkes realised that basic and frequently used operations could be programmed directly into hardware*

In 1956, IBM sold its first magnetic disk system, RAMAC (Random Access Method of Accounting and Control). It used 50 24-inch metal disks, with 100 tracks per side. It could store 5 megabytes of data and cost $10,000 per megabyte.

## Second Generation Computers (1950s and early 1960s)

The next major step in the history of computing was the invention of the transistor in 1947. This replaced the fragile and power hungry valves with a much smaller and more reliable component. Transistorized computers are normally referred to as 'Second Generation' and dominated the late 1950s and early 1960s. By using transistors and printed circuits a significant decrease in size and power consumption was achieved, along with an increase in reliability. For example, the transistorized IBM 1620, which replaced the bulky IBM 650, was the size of an office desk. Second generation computers were still expensive and were primarily used by universities, governments, and large corporations.

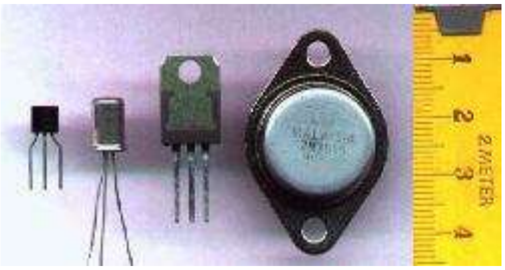

*Figure 1-16 - Transistors, above, revolutionized computers as smaller and more efficient replacements for vacuum tubes*

In 1959, IBM shipped the transistor-based IBM 7090 mainframe and medium scale IBM 1401. The latter was designed around punch card input and proved a popular general purpose computer. Some 12,000 were shipped, making it the most successful machine in computer history at the time. It used a magnetic core memory of 4,000 characters (later expanded to 16,000 characters). Many aspects of its design were based on the desire to replace punched card machines which were in wide use from the 1920s through the early 1970s.

In 1960, IBM shipped the smaller, transistor-based IBM 1620, originally with only punched paper tape, but soon upgraded to punch cards. It proved a popular scientific computer and about 2,000 were shipped. It used a magnetic core memory of up to 60,000 decimal digits.

Also in 1960, DEC launched the PDP-1 - their first machine intended for use by technical staff in laboratories and for research.

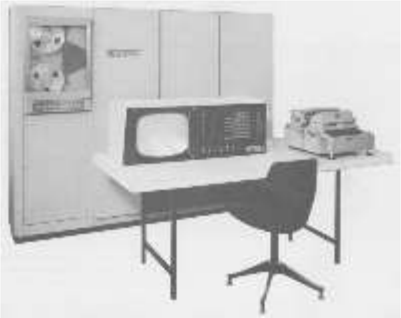

*Figure 1-17 - Digital Equipment Corporation's first computer was the PDP-1. It was built mostly of DEC 1000-series system modules, using Micro-Alloy and Micro-Alloy-Diffused Transistors*

In 1961, Burroughs released the B5000 the first dual processor and virtual memory computer. Other unique features were a stack architecture, descriptor-based addressing, and no programming directly in assembly language.

In 1962, Sperry Rand shipped the UNIVAC 1107, one of the first machines with a general register set and the base of the successful UNIVAC 1100 series.

In 1964 IBM announced the S/360 series, which was the first family of computers that could run the same software at different combinations of speed, capacity and price. It also pioneered the commercial use of microprograms, and an extended instruction set designed for processing many types of data, not just arithmetic. In addition, it unified IBM's product line, which prior to that time had included both a "commercial" product line and a separate "scientific" line. The software provided with System/360 also included major advances, including commercially available multi-programming, new programming languages, and independence of programs from input/output devices. Over 14,000 System/360 systems were shipped by 1968.

Also in 1964, DEC launched the PDP-8, which was a much smaller machine intended for use by technical staff in laboratories and for research.

## Third Generation Computers and beyond (Post 1960)

The explosion in the use of computers began with 'Third Generation' computers. These relied on Jack St. Clair Kilby's and Robert Noyce's independent invention of the integrated circuit (or microchip), which later led to Ted Hoff's invention of the microprocessor, at Intel.

During the 1960s there was considerable overlap between second and third generation technologies. As late as 1975, Sperry Univac continued the manufacture of second-generation machines such as the UNIVAC 494.

The microprocessor led to the development of the microcomputer - small, low-cost computers that could be owned by individuals and small businesses. Microcomputers, the first of which appeared in the 1970s, became ubiquitous in the 1980s and beyond.

# Chapter 2

## Programming Languages

The first programming languages predate the modern computer. Herman Hollerith (see *Figure 1-6*) realized that he could encode information on punch cards when he observed that railroad train conductors would encode the appearance of the ticket holders on the train tickets using the position of punched holes on the tickets. Hollerith then proceeded to encode the 1890 census data on punch cards which he made the same size as the boxes for holding US currency. (The dollar bill was later downsized.)

The first computer codes were specialized for the applications. In the first decades of the twentieth century, numerical calculations were based on decimal numbers. Eventually it was realized that logic could be represented with numbers, as well as with words. For example, Alonzo Church was able to express the lambda calculus in a formulaic way. The Turing machine was an abstraction of the operation of a tape-marking machine, for example, in use at the telephone conference calling companies. However, unlike the lambda calculus, Turing's code does not serve well as a basis for higher-level languages - its principal use is in rigorous analyses of algorithmic complexity.

Like many "firsts" in history, the first modern programming language is hard to identify. From the start, the restrictions of the hardware defined the language. Punch cards allowed 80 columns, but some of the columns had to be used for a sorting number on each card. Fortran included some keywords that were the same as English words, such as "IF", "GOTO" (go to) and "CONTINUE". The use of a magnetic drum for memory meant that computer programs also had to be interleaved with the rotations of the drum. Thus the programs were more hardware dependent than today.

To some people the answer depends on how much power and human-readability is required before the status of "programming language" is granted. Jacquard looms and Charles Babbage's Difference Engine both had simple, extremely limited languages for describing the actions that these machines should perform. One can even regard the punch holes on a player piano scroll as a limited domain-specific programming language, albeit not designed for human consumption.

### The 1940s

In the 1940s the first recognizably modern, electrically powered computers were created. The limited speed and memory capacity forced programmers to write hand tuned assembly language programs. It was soon discovered that programming in assembly language required a great deal of intellectual effort and was error-prone.

In 1945, Konrad Zuse published details of his programming language Plankalkül. However, it was not implemented in his time and his original contributions were isolated from other developments because Germany was isolated during the war.

Some important languages that were developed in this time period include:

- 1943 - Plankalkül (Konrad Zuse)
- 1943 - ENIAC coding system
- 1949 - C-10

## The 1950s and 1960s

In the 1950s the first three modern programming languages, whose descendants are still in widespread use today, were designed:

- FORTRAN, the "FORmula TRANslator", invented by John W. Backus et al.
- LISP, the "LISt Processor", invented by John McCarthy et al.
- COBOL, the COmmon Business Oriented Language, created by the Short Range Committee, heavily influenced by Grace Hopper

Another milestone in the late 1950s was the publication, by a committee of American and European computer scientists, of "a new language for algorithms"; the Algol 60 Report (the "ALGOrithmic Language"). This report consolidated many ideas circulating at the time and featured two key innovations:

- The use of Backus-Naur Form (BNF) for describing the language's syntax. Nearly all subsequent programming languages have used a variant of BNF to describe the context-free portion of their syntax.
- The introduction of lexical scoping for names in arbitrarily nested scopes.

Algol 60 was particularly influential in the design of later languages, some of which soon became more popular. The Burroughs B5000 was designed to be programmed in an extended subset of Algol.

Some important languages that were developed in this time period include:

- 1951 - Regional Assembly Language
- 1952 - Autocode
- 1954 - FORTRAN
- 1958 - LISP
- 1958 - ALGOL
- 1959 - COBOL
- 1962 - APL
- 1962 - Simula

- 1964 - BASIC
- 1964 - PL/I

## 1967-1978: Establishing Fundamental Paradigms

The period from the late 1960s to the late 1970s brought a major flowering of programming languages. Most of the major language paradigms now in use were invented in this period:

- Simula, invented in the late 1960s by Nygaard and Dahl as a superset of Algol 60, was the first language designed to support object-oriented programming. Smalltalk (mid 1970s) provided a complete ground-up design of an object-oriented language.
- C, an early systems programming language, was developed by Dennis Ritchie and Ken Thompson at Bell Labs between 1969 and 1973.
- Prolog, designed in 1972 by Colmerauer, Roussel, and Kowalski, was the first logic programming language.
- ML built a polymorphic type system (invented by Robin Milner in 1978) on top of Lisp, pioneering statically typed functional programming languages.

Each of these languages spawned an entire family of descendants, and most modern languages count at least one of them in their ancestry.

The 1960s and 1970s also saw considerable debate over the merits of "structured programming", which essentially meant programming without the use of GOTO. This debate was closely related to language design: some languages did not include GOTO, which forced structured programming on the programmer. Although the debate raged hotly at the time, nearly all programmers now agree that, even in languages that provide GOTO, it is bad style to use it except in rare circumstances. As a result, later generations of language designers have found the structured programming debate tedious and even bewildering.

Some important languages that were developed in this time period include:

- 1968 - Logo
- 1969 - B (forerunner to C)
- 1970 - Pascal
- 1970 - Forth
- 1972 - C
- 1972 - Smalltalk
- 1972 - Prolog
- 1973 - ML
- 1975 - Scheme
- 1978 - SQL (a query language, later extended)

## The 1980s: Consolidation, Modules, and Performance

The 1980s were years of relative consolidation. C++ combined object-oriented and systems programming. The United States government standardized Ada, a systems programming language intended for use by defense contractors. In Japan and elsewhere, vast sums were spent investigating so-called "fifth generation" languages that incorporated logic programming constructs. The functional languages community moved to standardize ML and Lisp. Rather than inventing new paradigms, all of these movements elaborated upon the ideas invented in the previous decade.

However, one important new trend in language design was an increased focus on programming for large-scale systems through the use of modules, or large-scale organizational units of code. Modula, Ada, and ML all developed notable module systems in the 1980s. Module systems were often wedded to generic programming constructs - generics being, in essence, parameterized modules.

Although major new paradigms for programming languages did not appear, many researchers expanded on the ideas of prior languages and adapted them to new contexts. For example, the languages of the Argus and Emerald systems adapted object-oriented programming to distributed systems.

The 1980s also brought advances in programming language implementation. The RISC movement in computer architecture postulated that hardware should be designed for compilers rather than for human assembly programmers. Aided by processor speed improvements that enabled increasingly aggressive compilation techniques, the RISC movement sparked greater interest in compilation technology for high-level languages.

Language technology continued along these lines well into the 1990s. However, the adoption of languages has always been driven by the adoption of new computer systems, and in the mid-1990s one of the most important new systems in computer history suddenly exploded in popularity.

Some important languages that were developed in this time period include:

- 1980 - C++ (as C with classes, renamed in 1983)
- 1983 - Ada
- 1984 - Common Lisp
- 1984 - MATLAB
- 1985 - Eiffel
- 1986 - Objective-C
- 1986 - Erlang
- 1987 - Perl
- 1988 - Tcl
- 1988 - Mathematica
- 1989 - FL (Backus)

## The 1990s: The Internet Age

The rapid growth of the Internet in the mid-1990s was the next major historic event in programming languages. By opening up a radically new platform for computer systems, the Internet created an opportunity for new languages to be adopted. In particular, the Java programming language rose to popularity because of its early integration with the Netscape Navigator web browser, and various scripting languages achieved widespread use in developing customized applications for web servers. Many computer information systems degree courses today teach Java as well as other programming languages. Neither of these developments represented much fundamental novelty in language design; for example, the design of Java was a more conservative version of ideas explored many years earlier in the Smalltalk community, but the widespread adoption of languages that supported features like garbage collection and strong static typing was a major change in programming practice.

Some important languages that were developed in this time period include:

- 1990 - Haskell
- 1991 - Python
- 1991 - Visual Basic
- 1993 - Ruby
- 1993 - Lua
- 1994 - CLOS (part of ANSI Common Lisp)
- 1995 - Ada 95
- 1995 - Java
- 1995 - Delphi (Object Pascal)
- 1995 - JavaScript
- 1995 - PHP
- 1996 - WebDNA
- 1997 - Rebol
- 1999 - D

## Current Trends

Programming language evolution continues in both industry and research, and is used in industries ranging from security cameras to televisions. Some current directions:

- Mechanisms for adding security and reliability verification to the language: extended static checking, information flow control, static thread safety.
- Alternative mechanisms for modularity: mixins, delegates, aspects.
- Component-oriented software development.
- Increased emphasis on distribution and mobility.
- Integration with databases, including XML and relational databases.
- Open Source as a developmental philosophy for languages, including recent languages such as Python, Ruby, and Squeak.
- Support for Unicode so that source code (program text) is not restricted to those characters contained in the ASCII character set; allowing, for example, use of non-Latin-based scripts or extended punctuation.

Some important languages developed during this period include:

- 2000 - ActionScript
- 2001 - C#
- 2001 - Visual Basic .NET
- 2002 - F#
- 2003 - Groovy
- 2003 - Scala
- 2007 - Clojure
- 2009 - Go
- 2011 - Dart
- 2012 - Rust
- 2014 - Swift

# Chapter 3

## The Microprocessor

A microprocessor (sometimes abbreviated µP) is a digital electronic component with transistors on a single semiconductor integrated circuit (IC). One or more microprocessors typically serve as a central processing unit (CPU) in a computer system or handheld device.

Microprocessors made possible the advent of the microcomputer. Before this, electronic CPUs were typically made from bulky discrete switching devices (and later small-scale integrated circuits) containing the equivalent of only a few transistors.

By integrating the processor onto one or a very few large-scale integrated circuit packages (containing the equivalent of thousands or millions of discrete transistors), the cost of processor power was greatly reduced. Since the advent of the IC in the mid-1970s, the microprocessor has become the most prevalent implementation of the CPU, nearly completely replacing all other forms.

*Figure 3-1 – A Collection of Microprocessors*

The evolution of microprocessors has been known to follow Moore's Law when it comes to steadily increasing performance over the years. This law suggests that the complexity of an integrated circuit, with respect to minimum component cost, doubles every 24 months. This dictum has generally proven true since the early 1970s.

From their humble beginnings as the drivers for calculators, the continued increase in power has led to the dominance of microprocessors over every other form of computer; every system from the largest mainframes to the smallest handheld computers now uses a microprocessor at its core.

Microprocessors have impacted every type of computer that we use in our daily lives, from giving students studying for their bachelor degree online the ability do so anywhere at any time, to being able to find your travel destination using GPS.

Without the introduction of microprocessors the computers we now have in our homes and even the one on your desk in your office would be vastly inferior to what we are accustomed to today. Simple tasks such as browsing the web and using word processors would be a monumental task.

## History of the Microprocessor

As with many advances in technology, the microprocessor was an idea whose time had come. Three projects arguably delivered a complete microprocessor at about the same time, Intel's 4004, Texas Instruments' TMS 1000, and Garrett AiResearch's Central Air Data Computer.

In 1968, Garrett was invited to produce a digital computer to compete with electromechanical systems then under development for the main flight control computer in the US Navy's new F-14 Tomcat fighter. The design was complete by 1970, and used a MOS-based chipset as the core CPU. The design was smaller and much more reliable than the mechanical systems it competed against, and was used in all of the early Tomcat models. However, the system was considered so advanced that the Navy refused to allow publication of the design, and continued to refuse until 1997. For this reason the CADC, and the MP944 chipset it used, are fairly unknown even today. Thanks to these beginnings and the use of geographic information technology, we now have GPS systems in our cars and phones that are readily available for our needs. The Navy's systems may be more advanced than what we have available to the public but its due to the microprocessors that we even have them at all.

Texas Instruments (TI) developed the 4-bit TMS 1000 and stressed pre-programmed embedded applications, introducing a version called the TMS1802NC on September 17, 1971, which implemented a calculator on a chip. The Intel chip was the 4-bit 4004, released on November 15, 1971, developed by Federico Faggin.

TI filed for the patent on the microprocessor. Gary Boone was awarded U.S. Patent 3,757,306 for the single-chip microprocessor architecture on September 4, 1973. It may never be known which company actually had the first working microprocessor running on the lab bench. In both 1971 and 1976, Intel and TI entered into broad patent cross-licensing agreements, with Intel paying royalties to TI for the microprocessor patent. A nice history of these events is contained in court documentation from a legal dispute between Cyrix and Intel, with TI as intervenor and owner of the microprocessor patent.

A computer-on-a-chip is a variation of a microprocessor which combines the microprocessor core (CPU), some memory, and I/O (input/output) lines, all on one chip. The computer-on-a-chip patent, called the "microcomputer patent" at the time, U.S. Patent 4,074,351, was awarded to Gary Boone and Michael J. Cochran of TI. Aside from this patent, the standard meaning of microcomputer is a computer using one or more microprocessors as its CPU(s), while the concept defined in the patent is perhaps more akin to a microcontroller.

According to A History of Modern Computing, (MIT Press), pp. 220-21, Intel entered into a contract with Computer Terminals Corporation, later called Datapoint, of San Antonio TX, for a chip for a terminal they were designing. Datapoint later decided not to use the chip, and Intel marketed it as the 8008 in April 1972. This was the world's first 8-bit microprocessor. It was the basis for the famous "Mark-8" computer kit advertised in the magazine Radio-Electronics in 1974. The 8008 and its successor, the world-famous 8080, opened up the microprocessor component marketplace.

## 8-bit Designs

The 4004 was later followed in 1972 by the 8008, the world's first 8-bit microprocessor. These processors are the precursors to the very successful Intel 8080 (1974), Zilog Z80 (1976), and derivative Intel 8-bit processors. The competing Motorola 6800 was released in August 1974. Its architecture was cloned and improved in the MOS Technology 6502 in 1975, rivaling the Z80 in popularity during the 1980s.

Both the Z80 and 6502 concentrated on low overall cost, through a combination of small packaging, simple computer bus requirements, and the inclusion of circuitry that would normally have to be provided in a separate chip (for instance, the Z80 included a memory controller). It was these features that allowed the home computer "revolution" to take off in the early 1980s, eventually delivering semi-usable machines that sold for US$99.

The Western Design Center, Inc. (WDC) introduced the CMOS 65C02 in 1982 and licensed the design to several companies, which became the core of the Apple IIc and IIe personal computers, medical implantable grade pacemakers and defibrilators, automotive, industrial and consumer devices. WDC pioneered the licensing of microprocessor technology, which was later followed by ARM and other microprocessor Intellectual Property (IP) providers in the 1990s.

Motorola trumped the entire 8-bit world by introducing the MC6809 in 1978, arguably one of the most powerful, orthogonal, and clean 8-bit microprocessor designs ever fielded - and also one of the most complex hardwired logic designs that ever made it into production for any microprocessor. Microcoding replaced hardwired logic at about this point in time for all designs more powerful than the MC6809 - specifically because the design requirements were getting too complex for hardwired logic.

Another early 8-bit microprocessor was the Signetics 2650, which enjoyed a brief flurry of interest due to its innovative and powerful instruction set architecture.

A seminal microprocessor in the world of spaceflight was RCA's RCA 1802 (aka CDP1802, RCA COSMAC) (introduced in 1976) which was used in NASA's Voyager and Viking spaceprobes of the 1970s, and onboard the Galileo probe to Jupiter (launched 1989, arrived 1995). RCA COSMAC was the first to implement C-MOS technology. The CDP1802 was used because it could be run at very low power, and because its production process (Silicon on Sapphire) ensured much better protection against cosmic radiation and electrostatic discharges than that of any other processor of the era. Thus, the 1802 is said to be the first radiation-hardened microprocessor.

## 16-bit Designs

The first multi-chip 16-bit microprocessor was the National Semiconductor IMP-16, introduced in early 1973. An 8-bit version of the chipset was introduced in 1974 as the IMP-8. In 1975, National introduced the first 16-bit single-chip microprocessor, the PACE, which was later followed by an NMOS version, the INS8900.

Other early multi-chip 16-bit microprocessors include one used by Digital Equipment Corporation (DEC) in the LSI-11 OEM board set and the packaged PDP 11/03 minicomputer, and the Fairchild Semiconductor MicroFlame 9440, both of which were introduced in the 1975 to 1976 timeframe.

The first single-chip 16-bit microprocessor was TI's TMS 9900, which was also compatible with their TI 990 line of minicomputers. The 9900 was used in the TI 990/4 minicomputer, the TI-99/4A home computer, and the TM990 line of OEM microcomputer boards. The chip was packaged in a large ceramic 64-pin DIP package, while most 8-bit microprocessors such as the Intel 8080 used the more common, smaller, and less expensive plastic 40-pin DIP. A follow-on chip, the TMS 9980, was designed to compete with the Intel 8080, had the full TI 990 16-bit instruction set, used a plastic 40-pin package, moved data 8 bits at a time, but could only address 16KB. A third chip, the TMS 9995, was a new design. The family later expanded to include the 99105 and 99110.

The Western Design Center, Inc. (WDC) introduced the CMOS 65816 16-bit upgrade of the WDC CMOS 65C02 in 1984. The 65816 16-bit microprocessor was the core of the Apple IIgs and later the Super Nintendo Entertainment System, making it one of the most popular 16-bit designs of all time.

Intel followed a different path, having no minicomputers to emulate, and instead "upsized" their 8080 design into the 16-bit Intel 8086, the first member of the x86 family which powers most modern PC type computers. Intel introduced the 8086 as a cost effective way of porting software from the 8080 lines, and succeeded in winning a lot of business on that premise. The 8088, a version of the 8086 that used an external 8-bit data bus, was the microprocessor in the first IBM PC, the model 5150. Following up their 8086 and 8088, Intel released the 80186, 80286 and, in 1985, the 32-bit 80386, cementing their PC market dominance with the processor family's backwards compatibility.

The integrated microprocessor memory management unit (MMU) was developed by Childs et al. of Intel, and awarded US patent number 4,442,484.

## 32-bit Designs

16-bit designs were in the market only briefly when full 32-bit implementations started to appear.

The world's first single-chip 32-bit microprocessor was the AT&T Bell Labs BELLMAC-32A, with first samples in 1980, and general production in 1982. After the divestiture of AT&T in 1984, it was renamed the WE 32000 (WE for Western Electric), and had two follow-on generations, the WE 32100 and WE 32200. These microprocessors were used in the AT&T 3B5 and 3B15 minicomputers; in the 3B2, the world's first desktop supermicrocomputer; in the "Companion", the world's first 32-bit laptop computer; and in "Alexander", the world's first book-sized supermicrocomputer, featuring ROM-pack memory cartridges similar to recent gaming consoles. All these systems ran the original Bell Labs Unix Operating System, which included the first Windows-type software called xt-layers.

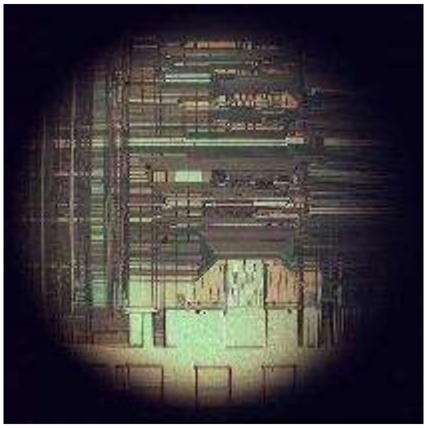

*Figure 3-2 - Upper Interconnect Layers on an Intel 80486 DX2 Microprocessor*

The most famous of the 32-bit designs is the MC68000, introduced in 1979. The 68K, as it was widely known, had 32-bit registers but used 16-bit internal data paths, and a 16-bit external data bus to reduce pin count. Motorola generally described it as a 16-bit processor, though it clearly has 32-bit architecture. The combination of high speed, large (16 megabyte) memory space and fairly low costs made it the most popular CPU design of its class. The Apple Lisa and Macintosh designs made use of the 68000, as did a host of other designs in the mid-1980s, including the Atari ST and Commodore Amiga.

Intel's first 32-bit microprocessor was the iAPX 432, which was introduced in 1981 but was not a commercial success. It had an advanced capability-based object-oriented architecture, but poor performance compared to other competing architectures such as the Motorola 68000.

Motorola's success with the 68000 led to the MC68010, which added virtual memory support. The MC68020, introduced in 1985 added full 32-bit data and address busses. The 68020 became hugely popular in the Unix supermicrocomputer market, and many small companies (e.g., Altos, Charles River Data Systems) produced desktop-size systems. Following this with the MC68030, which added the MMU into the chip, the 68K family became the processor for everything that wasn't running DOS. The continued success led to the MC68040, which included an FPU for better math performance. A 68050 failed to achieve its performance goals and was not released, and the follow-up MC68060 was released into a market saturated by much faster RISC designs. The 68K family faded from the desktop in the early 1990s.

Other large companies designed the 68020 and follow-ons into embedded equipment. At one point there were more 68020s in embedded equipment than there were Intel Pentiums in PCs. The ColdFire processor cores are derivatives of the venerable 68020.

During this time (early to mid 1980s), National Semiconductor introduced a very similar 16-bit pinout, 32-bit internal microprocessor called the NS 16032 (later renamed 32016), the full 32-bit version named the NS 32032, and a line of 32-bit industrial OEM microcomputers. By the mid-1980s, Sequent introduced the first symmetric multiprocessor (SMP) server-class computer using the NS 32032. This was one of the design's few wins, and it disappeared in the late 1980s.

Other designs included the interesting Zilog Z8000, which arrived too late to market to stand a chance and disappeared quickly.

In the late 1980s, "microprocessor wars" started killing off some of the microprocessors. Apparently, with only one major design win, Sequent, the NS 32032 just faded out of existence, and Sequent switched to Intel microprocessors.

## 64-bit Microchips on the Desktop

While 64-bit microprocessor designs have been in use in several markets since the early 1990s, the early 2000s saw the introduction of 64-bit microchips targeted at the PC market.

With AMD's introduction of the first 64-bit IA-32 backwards-compatible architecture, AMD64, in September 2003, followed by Intel's own x86-64 chips, the 64-bit desktop era began. Both processors could run 32-bit legacy apps as well as newer 64-bit software. With 64-bit Windows XP and Linux that ran 64-bit native, the software too was geared to utilise the full power of such processors.

In reality the move to 64-bits was more than just an increase in register size from the ia32 as it also included a small increase in register quantity for the aging CISC designs.

The move to 64 bits by PowerPC processors had been intended since the processor's design in the early 90s and was not a major cause of incompatibility. Existing integer registers are extended as are all related data pathways but in common with the IA32 designs both floating point and vector units had been operating at or above 64 bits for several years. Unlike the IA32 no new general purpose registers are added so any performance gained when using the 64-bit mode is minimal.

In 2011, ARM introduced a new 64-bit ARM architecture.

## Multi-Core Designs

A different approach to improving a computer's performance is to add extra processors, as in symmetric multiprocessing designs, which have been popular in servers and workstations since the early 1990s. Keeping up with Moore's Law is becoming increasingly challenging as chip-making technologies approach their physical limits. In response, microprocessor manufacturers look for other ways to improve performance so they can maintain the momentum of constant upgrades.

A multi-core processor is a single chip that contains more than one microprocessor core. Each core can simultaneously execute processor instructions in parallel. This effectively multiplies the processor's potential performance by the number of cores, if the software is designed to take advantage of more than one processor core. Some components, such as bus interface and cache, may be shared between cores. Because the cores are physically close to each other, they can communicate with each other much faster than separate (off-chip) processors in a multiprocessor system, which improves overall system performance.

In 2005, AMD released the first native dual-core processor, the Athlon X2. Intel's Pentium D had beaten the X2 to market by a few weeks, but it used two separate CPU dies and was less efficient than AMD's native design. As of 2015, dual-core and quad-core processors are widely used in home PCs and laptops, while quad, six, eight, ten, twelve, and sixteen-core processors are common in the professional and enterprise markets with workstations and servers.

Modern desktop computers support systems with multiple CPUs, but few applications outside of the professional market can make good use of more than four cores. Both Intel and AMD currently offer fast quad- and six-core desktop CPUs, making multi CPU systems obsolete for many purposes. AMD also offers the first and currently the only eight core desktop CPUs with the FX-8xxx line.

## RISC

In the mid-1980s to early-1990s, a crop of new high-performance RISC (reduced instruction set computer) microprocessors appeared, which were initially used in special purpose machines and Unix workstations, but have since become almost universal in all roles except the Intel-standard desktop.

The first commercial design was released by MIPS Technologies, the 32-bit R2000 (the R1000 was not released). The R3000 made the design truly practical, and the R4000 introduced the world's first 64-bit design. Competing projects would result in the IBM POWER and Sun SPARC systems, respectively. Soon every major vendor was releasing a RISC design, including the AT&T CRISP, AMD 29000, Intel i860 and Intel i960, Motorola 88000, DEC Alpha and the HP-PA.

Market forces have "weeded out" many of these designs, leaving the PowerPC as the main desktop RISC processor, with the SPARC being used in Sun designs only. MIPS continues to supply some SGI systems, but is primarily used as an embedded design, notably in Cisco routers.

The rest of the original crop of designs have either disappeared, or are about to. Other companies have attacked niches in the market, notably ARM, originally intended for home computer use but since focussed at the embedded processor market. Today, RISC designs based on the MIPS, ARM or PowerPC core power the vast majority of computing devices.

In 64-bit computing, DEC Alpha, AMD64, MIPS, SPARC, Power Architecture, and HP-Intel Itanium are all popular designs.

## Special-Purpose Microprocessors

Though the term "microprocessor" has traditionally referred to a single- or multi-chip CPU or System-on-a-chip (SoC), several types of specialized processing devices have followed from the technology. The most common examples are microcontrollers, Digital Signal Processors (DSP) and Graphics processing units (GPU). Many examples of these are either not programmable, or have limited programming facilities. For example, in general GPUs through the 1990s were mostly non-programmable and have only recently gained limited facilities like programmable vertex shaders. There is no universal consensus on what defines a "microprocessor", but it is usually safe to assume that the term refers to a general-purpose CPU of some sort and not a special-purpose processor unless specifically noted.

The RCA 1802 had what is called a static design, meaning that the clock frequency could be made arbitrarily low, even to 0 Hz, a total stop condition. This let the Voyager/Viking/Galileo spacecraft use minimum electric power for long uneventful stretches of a voyage. Timers and/or sensors would awaken/speed up the processor in time for important tasks, such as navigation updates, attitude control, data acquisition, and radio communication.

# Chapter 4

## Operating Systems

The history of computer operating systems recapitulates to a degree, the recent history of computing.

A computer’s operating system (OS) provides a set of functions needed and used by most applications, and provides the necessary linkages to control a computer's hardware. On the first computers, without an operating system, each program would need its own drivers for the video card, memory card, and other peripherals. The evolution of computer applications and their complexity led to the OS necessities.

### Background

Early computers lacked any form of operating system. The user had sole use of the machine; he would arrive at the machine armed with his program and data, often on punched paper tape. The program would be loaded into the machine, and the machine set to work, until the program stopped, or maybe more likely, crashed. Programs could generally be debugged via a front panel using switches and lights; it is said that Alan Turing was a master of this on the early Manchester Mark I machine. He drew the seminal concepts of operating systems from the Universal Turing Machine concept.

Later, machines came with libraries of support code which were linked to the user's program to assist in operations such as input and output. This would become the genesis of the modern-day operating system. However, machines still ran a single job at a time; at Cambridge University in England the job queue was at one time a washing line from which tapes were hung with clothes pegs. The color of the pegs indicated the priority of the job.

As machines became more powerful, the time needed for a run of a program diminished and the time to hand off the equipment became very large by comparison. Accounting for and paying for machine usage went from checking the wall clock to using the computer to do the timing. Run queues went from being people waiting at the door to stacks of media waiting on a table to using the hardware of the machine such as switching which magnetic tape drive was online or stacking punch cards on top of the previous jobs cards in the reader.

Operating the computer went from a task performed by the program developer to a job for full time dedicated machine operators. When commercially available computer centers found they had to deal with accidental or malicious tampering of the accounting information, equipment vendors were encouraged to enhance the properties of the runtime libraries to prevent misuse of the systems resources.

Accounting practices were also expanded beyond recording CPU usage to also count pages printed, cards punched, cards read, disk storage used, and even operator action required by jobs such as changing magnetic tapes.

Eventually, the runtime libraries became a program that was started before the first customer job, that read in the customer job, controlled its execution, cleaned up after it, recorded its usage, and immediately went on to process the next job.

Jobs also evolved from being binary images produced by hand encoding to symbolic programs that were translated by the computer. An operating system, or "monitor" as it was sometimes called, permitted jobs to become multistep with the monitor running several programs in sequence to effect the translation and subsequent run of the user's program.

The conceptual bridge between the precise description of an operating system and the colloquial definition is the tendency to bundle widely, or generally, used utilities and applications (such as text editors or file managers) with the basic OS for the sake of convenience; as OSes progressed, a larger selection of 'second class' OS software came to be included, such that now, an OS without a graphical user interface or various file viewers is often considered not to be a true or complete OS. To accommodate this evolution of the meaning, most of what was the original "operating system" is now called the "kernel", and OS has come to mean the complete package.

## The Mainframe Era

Early operating systems were very diverse, with each vendor producing one or more operating systems specific to their particular hardware. Every operating system, even from the same vendor, could have radically different models of commands, operating procedures, and such facilities as debugging aids. Typically, each time the manufacturer brought out a new machine, there would be a new operating system. This state of affairs continued until the 1960s when IBM developed the System/360 series of machines which all used the same instruction architecture. Because there were enormous performance differences across the range, a single operating system could not be used and a family of operating systems were developed. (The problems encountered in the development of the OS/360 are legendary, and are described by Fred Brooks in The Mythical Man-Month - a book that has become a classic of software engineering.)

OS/360 evolved to become successively MFT, MVT, SVS, MVS, MVS/XA, MVS/ESA, OS/390 and z/OS, which includes the UNIX kernel as well as a huge amount of new functions required by modern mission-critical applications running on the zSeries mainframes. It is worth mentioning that IBM maintained full compatibility with the past, so that programs developed in the sixties can still run under z/OS with no change. Although z/OS runs UNIX applications, it is a proprietary OS, in opposition to an Open System.

Control Data Corporation developed the Scope operating system in the 1960s for batch processing. In cooperation with the University of Minnesota, the KRONOS and later the NOS operating systems were developed during the 1970s, which supported simultaneous batch and timesharing use. Like many commercial timesharing systems, its interface was an extension of the Dartmouth BASIC operating systems, one of the pioneering efforts in timesharing and programming languages. In the late 1970s, Control Data and the University of Illinois developed the PLATO operating system, which used plasma planel displays and long-distance time sharing networks. Plato was remarkably innovative for its time, featuring real-time chat, and multi-user graphical games.

UNIVAC, the first commercial computer manufacturer, produced a series of EXEC operating systems. Like all early main-frame systems, this was a batch-oriented system that managed magnetic drums, disks, card readers and line printers. In the 1970s, UNIVAC produced the Real-Time Basic (RTB) system to support large-scale time sharing, also patterned after the Dartmouth BASIC system.

Digital Equipment Corporation developed many operating systems for its various computer lines, including the simple RT-11 system for its 16-bit PDP-11 class machines, the VMS system for the 32-bit VAX computer, and TOPS-10 and TOPS-20 time sharing systems for the 36-bit PDP-10 class systems. Prior to the widespread use of UNIX, TOPS-10 was a particularly popular system in universities, and in the early ARPANET community.

## Minicomputers and the Rise of UNIX

The UNIX operating system was developed at AT&T Bell Laboratories in the 1970s. Because it was essentially free in early editions, easily obtainable, and easily modified, it achieved wide acceptance. It also became a requirement within the Bell systems operating companies. Since it was written in a high level language, when that language was ported to a new machine architecture UNIX was also able to be ported. This portability permitted it to become the choice for a second generation of minicomputers and the first generation of workstations. By widespread use it exemplified the idea of an operating system that was conceptually the same across various hardware platforms. It was still owned by AT&T and that limited its use to those groups or corporations who could afford to license it.

Many early operating systems were collections of utilities to allow users to run software on their systems. There were some companies who were able to develop better systems, such as early Digital Equipment Corporation systems, but others never supported features that were useful on other hardware types.

In the late 1960s through the late 1970s, several hardware capabilities evolved that allowed similar or ported software to run on more than one system. Early systems had utilized microprogramming to implement features on their systems in order to permit different underlying architecture to appear to be the same as others in a series. In fact most 360s after the 360/40 (except the 360/165 and 360/168) were microprogrammed implementations.

One system that evolved in this time frame was the Pick operating system. The Pick system was developed and sold by Microdata Corporation, and Dick Pick, who created the precursors of the system with an associate, Don Nelson. The system is an example of a system which started as a database application support program, graduated to system work, and still exists across a wide variety of systems supported on most UNIX systems as an addon database system.

Other packages such as Oracle are middleware and contain many of the features of operating systems, but are in fact large applications supported on many hardware platforms.

As hardware was packaged in ever larger amounts in small packages, first the bit slice level of integration in systems, and then entire systems came to be present on a single chip. This type of system in small 4 and 8 bit processors came to be known as microprocessors. Most were not microprogrammed, but were completely integrated general purpose processors.

## Home Computers

Although most of the smallest 8-bit home computers of the 1980s, such as the Commodore 64, the Amstrad CPC, ZX Spectrum series and others could use a "normal" disk-loading operating system, such as CP/M or GEOS, they could generally work without one. In fact, most if not all of these computers shipped with a built-in BASIC interpreter on ROM, which also served as a crude operating system, allowing minimal file management operations (such as deletion, copying, etc.) to be performed and sometimes disk formatting, along of course with application loading and execution, which sometimes required a non-trivial command sequence, like with the Commodore 64.

The fact that the majority of these machines were bought for entertainment and educational purposes and were seldom used for more "serious" or business/science oriented applications, partly explains why a "true" operating system was not necessary.

Another reason is that they were usually single-task and single-user machines and shipped with minimal amounts of RAM, usually between 4 and 256 kilobytes, with 64 and 128 being common figures, and 8-bit processors, so an operating system's overhead would likely compromise the performance of the machine without really being necessary.

Even the rare word processor and office suite applications were mostly self-contained programs that took over the machine completely, as also did videogames.

Finally, most of these machines didn't even ship with a built-in flexible disk drive, which made using a disk-based OS impossible or a luxury option.

## Game Consoles and Video Games

Since virtually all video game consoles and arcade cabinets designed and built after 1980 were true digital machines (unlike the analog PONG clones and derivatives), some of them carried a minimal form of BIOS or built-in game, such as the Colecovision, the Sega Master System and the SNK Neo Geo. There were however successful designs where a BIOS was not necessary, such as the Nintendo NES and its clones.

More recent game consoles and videogames, starting from the PlayStation all have a minimal BIOS that also provides some interactive utilities such as memory card management, audio or video CD playback, copy prevention and sometimes carry libraries for developers to use, etc. Few of these cases, however, would qualify as a "true" operating system.

The most notable exceptions are probably the Dreamcast game console which includes a minimal BIOS, like the PlayStation, but can load the Windows CE operating system from the game disk allowing easily porting of games from the PC world, and the Xbox game console, which is little more than a disguised Intel-based PC running a secret, modified version of Microsoft Windows in the background.

Furthermore, there are Linux versions that will run on a PlayStation or Xbox and maybe other game consoles as well, provided they have access to a large mass storage device and have a reasonable amount of RAM (the bare minimum for a GUI is around 512 kilobytes, as the case of the Commodore Amiga or early ATARI ST shows. GEOS however ran on a stock C64 which came with as little as 64 kilobytes).

Long before that, Sony had released a kind of development kit called the Net Yaroze for its first PlayStation platform, which provided a series of programming and developing tools to be used with a normal PC and a specially modified "Black PlayStation" that could be interfaced with a PC and download programs from it. These operations require in general a functional OS on both platforms involved.

In general, it can be said that videogame consoles and arcade coin operated machines used at most a built-in BIOS during the 1970s, 1980s and most of the 1990s, while from the PlayStation era and beyond they started getting more and more sophisticated, to the point of requiring a generic or custom-built OS for aiding in developing and expandability.

## The Personal Computer Era: Apple, DOS and Beyond

The development of microprocessors made inexpensive computing available for the small business and hobbyist, which in turn led to the widespread use of interchangeable hardware components using a common interconnection (such as the S-100, SS-50, Apple II, ISA, and PCI buses), and an increasing need for 'standard' operating systems to control them. The most important of the early OSes on these machines was Digital Research's CP/M-80 for the 8080 / 8085 / Z-80 CPUs. It was based on several Digital Equipment Corporation operating systems, mostly for the PDP-11 architecture. MS-DOS (or PC-DOS when supplied by IBM) was based originally on CP/M-80. Each of these machines had a small boot program in ROM which loaded the OS itself from disk. The BIOS on the IBM-PC class machines was an extension of this idea and has accreted more features and functions in the 20 years since the first IBM-PC was introduced in 1981.

The decreasing cost of display equipment and processors made it practical to provide graphical user interfaces for many operating systems, such as the generic X Window System that is provided with many UNIX systems, or other graphical systems such as Microsoft Windows, the RadioShack Color Computer's OS-9, Commodore's AmigaOS, Level II, Apple's Mac OS, or even IBM's OS/2. The original GUI was developed at Xerox Palo Alto Research Center in the early '70s (the Alto computer system) and was imitated by many vendors.

# Chapter 5

## Computer Games

Although the history of computer and video games spans five decades, computer and video games themselves did not become part of the popular culture until the late 1970s. Over the past three or four decades, video games have become extremely popular, either in the form of hand held consoles, or with games that run on computers or attached to TVs. The range of games available is also immense, with action, strategy, adventure, and sports games being very popular. In this chapter we will look at how computer and other video games have evolved since the 1960s.

### Computer Games: The Beginning

1947 is believed to be the year when the first game was designed for playing on a Cathode Ray Tube (CRT). This very simple game was designed by Thomas T. Goldsmith Jr. and Estle Ray Mann. A patent application was filed on January 25th, 1947 and U.S. Patent #2 455 992 issued on Dec 14th, 1948.

Though the filing date was in 1947, the game was probably designed earlier in 1946. The system used eight vacuum tubes (four 6Q5 triodes and four 6V6 tetrodes) and simulated a missile being fired at a target, probably inspired by radar displays used during World War II. Several knobs allowed for adjusting the curve and speed of the moving point representing the missile. Because graphics could not be drawn electronically at the time, small targets drawn on a simple overlay were placed on the CRT by the builder of this game. It is believed to be the earliest system specifically designed for game play on a CRT screen.

A.S. Douglas developed OXO - a graphical version of noughts and crosses (tic-tac-toe) - in 1952 at the University of Cambridge in order to demonstrate his thesis on human-computer interaction. It was played on the now archaic EDSAC computer, which used a cathode ray tube for a visual display. In spite of its technological antiquity, the game is still playable on an emulator available on the Internet.

Many people attribute the invention of the video game to William Higinbotham, who, in 1958, created a game called Tennis for Two on an oscilloscope to entertain visitors at Brookhaven National Laboratory in New York. Unlike Pong and similar early games, Tennis for Two shows a simplified tennis court from the side. The ball is affected by gravity and must be played over the net. The game is played with two bulky controllers each equipped with a knob for trajectory and a button for firing the ball over the net. Tennis for Two was exhibited for two seasons before its dismantling in 1959.

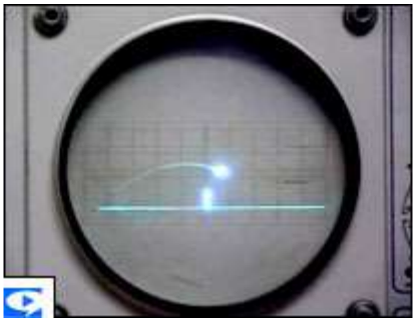

*Figure 5-1 – Tennis for Two*

## The 1960s

Many of the earliest computer games ran on university mainframes in the United States and were developed by individual users who programmed them in their spare time. However, the limited accessibility of early computer hardware meant that these games were few and easily forgotten by posterity.

In 1961, a group of students at MIT, including Steve Russell, programmed a game called Spacewar! on the then-new DEC PDP-1. The game pitted two human players against each other, each controlling a space ship capable of firing missiles. A black hole in the center created a large gravitational field and another source of hazard.

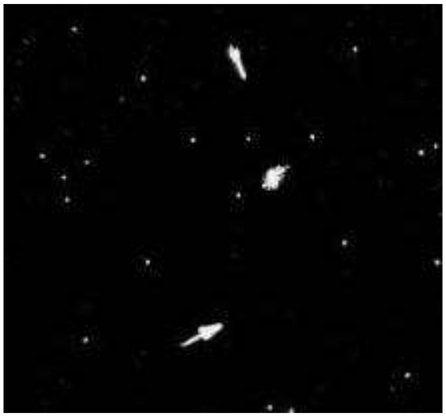

*Figure 5-2 – Spacewar!*

Spacewar! was soon distributed with new DEC computers and traded throughout primitive cyberspace. Presented at the MIT Science Open House in 1962, it was the first widely available and influential game.

One of the developers of Multics, Ken Thompson, continued to develop the operating system after AT&T stopped funding it. His work focused on development of the OS for the GE-645 mainframe. He actually wanted to play a game he was writing called Space Travel. Though the game was never released commercially (and apparently costing $75 per go on the mainframe), the game's development led to the invention of the UNIX operating system.

In 1966, Ralph Baer (then at Sanders Associates) created a simple video game called Chase that could be displayed on a standard television set. Baer continued development, and in 1968 he had a prototype that could play several different games, including versions of table tennis and target shooting. Under Baer, Bill Harrison developed the light gun and, with Bill Rusch, created video games in 1967.

## The 1970s

### Coin-Operated Games: Dawn of a Golden Age

By 1969 Ralph Baer had a working prototype console that hooked up to a TV set and played ball and paddle games. This prototype was sold to Magnavox who released it in May 1972 as the Odyssey - the world's first videogame console.

In 1971 Nolan Bushnell and Ted Dabney created a coin-operated arcade version of Spacewar! and called it Computer Space. Nutting Associates bought the game, hired Bushnell, and manufactured 1,500 Computer Space machines. The game was not a success because many people found it difficult to play.

Nolan Bushnell attended a demonstration of the Odyssey in Burlingame California in January 1972. He played video Ping-Pong but found it uninteresting and unimaginative.

As Bushnell felt he did not receive enough pay by licensing games to other manufacturers, he founded his own company, Atari, in 1972. The first arcade video game with widespread success was Atari's Pong, released the same year. The game is loosely based around table tennis: ball is "served" from the center of the court and as the ball moves towards their side of the court each player must manoeuvre their bat to hit the ball back to their opponent. Atari sold 19,000 Pong machines, and soon many imitators followed. The coin-operated arcade video game craze had begun.

Exidy's Death Race (1976) sparked the first controversy over gratuitous violence in a video game because the object of the game was to run over "gremlins" - who looked more like pedestrians - with a car. The controversy increased public awareness of video games and has never ceased to be debated.

The arcade game industry entered its Golden Age in 1978 with the release of Space Invaders by Taito. This game was a runaway blockbuster hit that inspired dozens of manufacturers to enter the market and produce their own video games. The Golden Age was marked by a prevalence of arcades and new color arcade games that continued through the 1980s.

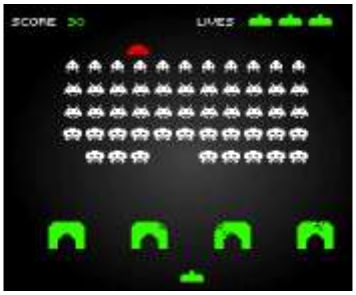

*Figure 5-3 – Space Invaders*

Also in 1978, Atari released Asteroids, its biggest best-seller. It replaced the game Lunar Lander as the number one arcade hit. Color arcade games became more popular in 1979 and 1980 (e.g. Pac-Man).

Other arcade classics of the late 1970s include Night Driver, Galaxian, and Breakout.

## Games on University Mainframe Computers

University mainframe game development blossomed in the early 1970s. The history of this era is difficult to write in a comprehensive way for several reasons:

- Until the late 1970s, game programmers never received any money for their work. The reward for designers of this era was praise from friends and an occasional fan letter from students at another university.
- There is little record of all but the most popular games, since they were played on machines which are no longer operated and saved on tapes that no longer exist.
- There were at least two major distribution networks for the student game designers of this time, and schools typically had access to only one brand of hardware and one supply of shared games. Many websites dedicated to the history of games focus solely on one system or the other, because the authors never had access to the "parallel universe" of the other hardware platform. The two largest systems were:
    - The PLATO System supported by Control Data Corporation under the support of William Norris and largely running on CDC mainframe computers, and
    - The DECUS software sharing system run by Digital Equipment Corporation for schools and other institutions utilizing DEC computers such as the PDP-10.

Highlights of this period, in approximate chronological order, include:

- 1971: Don Daglow wrote the first Computer Baseball game on a PDP-10 mainframe at Pomona College. Players could manage individual games or simulate an entire season. Daglow went on to team with programmer Eddie Dombrower to design Earl Weaver Baseball, published by Electronic Arts in 1987.

- 1971: Star Trek was created, probably by Mike Mayfield on a Sigma 7 minicomputer at MIT. This is the best-known and most widely played of the 1970s' Star Trek titles, and was played on a series of small "maps" of galactic sectors printed on paper or on the screen. It was the first major game to be ported across hardware platforms by students. Daglow also wrote a popular Star Trek game for the PDP-10 during 1971-72, which presented the action as a script spoken by the TV program's characters. A number of other Star Trek themed games were also available via PLATO and DECUS throughout the decade.

- 1972: Gregory Yob wrote Hunt the Wumpus for the PDP-10; a hide-and-seek game, though it could be considered the first text adventure. Yob wrote it in reaction to existing hide-and-seek games such as Hurkle, Mugwump, and Snark.

- 1974: Both Maze War (on the Imlacs PDS-1 at the NASA Ames Research Center in California) and Spasim (on PLATO) appeared, pioneering examples of early multi-player 3D first person shooters.

- 1975: Will Crowther wrote the first text adventure game as we would recognize it today, Adventure (originally called ADVENT, and later Colossal Cave). It was programmed in Fortran for the PDP-10. The player controls the game through simple sentence-like text commands and receives descriptive text as output. The game was later re-created by students on PLATO, so it is one of the few titles that became part of both the PLATO and PDP-10 traditions.

- 1975: Before the mid-1970s, games typically communicated to the player on paper, using teletype machines or a line printer, at speeds ranging from 10 to 30 characters per second with a rat-a-tat-tat sound as a metal ball or belt with characters was pressed against the paper through an inked ribbon by a hammer. By 1975 many universities had discarded these terminals for CRT screens, which could display thirty lines of text in a few seconds instead of the minute or more that printing on paper required. This led to the development of a series of games that drew "graphics" on the screen.

- 1975: Daglow, then a student at Claremont Graduate University, wrote the first Computer Role Playing Game on PDP-10 mainframes, Dungeon. The game was an unlicensed implementation of the new role playing game Dungeons and Dragons. Although displayed in text, it was the first game to use line of sight graphics, top-down dungeon maps that showed the areas that the party had seen or could see, allowing for light or darkness, the different vision of elves and dwarves, etc. 1975: At about the same time the RPG dnd, also based on Dungeons and Dragons first appeared on PLATO system CDC computers. For players in these schools dnd, not Dungeon, was the first computer role-playing game.

- 1977: Kelton Flinn and John Taylor create the first version of Air; a text air combat game that foreshadowed their later work, creating the first-ever graphical online multi-player game, Air Warrior. They would found the first successful online game company, Kesmai, now part of Electronic Arts. As Flinn has said: "If Air Warrior was a primate swinging in the trees, AIR was the text-based amoeba crawling on the ocean floor. But it was quasi-real time, multi-player, and attempted to render 3-D on the terminal using ASCII graphics. It was an acquired taste."

- 1977: The writing of the original Zork was started by Dave Lebling, Marc Blank, Tim Anderson, and Bruce Daniels. Unlike Crowther, Daglow and Yob, the Zork team recognized the potential to move these games to the new personal computers, and they founded text adventure publisher Infocom in 1979. The company was later sold to Activision. In a classic case of "connections", Lebling was a member of the same D&D group as Will Crowther, but not at the same time. Lebling has been quoted as saying "I think I actually replaced him when he dropped out. Zork was 'derived' from Advent in that we played Advent... and tried to do a 'better' one. There was no code borrowed... and we didn't meet either Crowther or Woods until much later."

- 1980: Michael Toy, Glenn Wichman and Ken Arnold released Rogue on BSD Unix after two years of work, inspiring many rogue like games ever since. Like Dungeon on the PDP-10 and did on PLATO, Rogue displayed dungeon maps using text characters. Unlike those games, however, the dungeon was randomly generated for each play session, so the path to treasure and the enemies who protected it were different for each game. As the Zork team had done, Rogue was adapted for home computers and became a commercial product.

## Early Handheld Games

The first portable, handheld electronic game was Tic Tac Toe, made in 1972 by a company called Waco. The display consisted of a grid of nine buttons that could turn red or green when pushed. The first handheld game console with interchangeable cartridges was the Microvision designed by Smith Engineering, and distributed and sold by Milton-Bradley in 1979. Crippled by a small, fragile LCD display and a very narrow selection of games, it was discontinued two years later. Although neither would prove popular, they paved the way for more advanced single-game handhelds, often simply called "LED games" or "LCD games" depending on their display system.

Mattel had seen car-race games in arcades and wanted to mass-produce something similar, but a video-game version would have been too costly. In 1974, Mattel engineers George Klose and Richard Cheng contracted with John Denker to write the Mattel Auto Race game as we know it, played on a 7x3 array of LED dots. Mark Lesser at Rockwell International Microelectronics Division ported the code to a calculator chip. The program was 512 bytes long. Subsequently, the same team produced Mattel Football I, which sold well over one million units and ushered in a short golden age of LED handheld games, especially sports games. At first composed of simple arrangements of LEDs, later games incorporated vacuum fluorescent displays allowing for detailed graphics in bright colors. The heyday of LED and VFD would last until the early 80s, when LCD technology became cheap and durable enough to be a viable alternative.

## Gaming on Home Computers

While the fruit of development in early video games appeared mainly (for the consumer) in video arcades and home consoles, the rapidly evolving home computers of the 1970s and 80s allowed their owners to program simple games. Hobbyist groups for the new computers soon formed and game software followed.

Soon many of these games (at first clones of mainframe classics such as Star Trek, and then later clones of popular arcade games) were being distributed through a variety of channels, such as printing the game's source code in books (such as David Ahl's Basic Computer Games), magazines (Creative Computing), and newsletters, which allowed users to type in the code for themselves. Early game designers like Crowther, Daglow and Yob would find the computer code for their games -- which they had never thought to copyright -- published in books and magazines, with their names removed from the listing. Early home computers from Apple, Commodore, Tandy and others had many games that people typed in.

Another distribution channel was the physical mailing and selling of floppy disks, cassette tapes and ROM cartridges. Soon a small cottage industry was formed, with amateur programmers selling disks in plastic bags put on the shelves of local shops, or sent through the mail. Richard Garriott distributed several copies of his 1980 computer role-playing game Akalabeth in plastic bags before the game was published.

## The First Home Video Games (1972-1977)

1972 also saw the release of the first video game console for the home market, the Magnavox Odyssey. Built using mainly analog electronics, it was based on Ralph Baer's earlier work and licensed from his employer. The console was connected to a home television set. It was not a large success, although other companies with similar products (including Atari) had to pay a licensing fee for some time. It wasn't until Atari's home version of Pong (at first under the Sears Tele-Games label) in Christmas of 1975 that home video games really took off. The success of Pong sparked hundreds of clone games, including the Coleco Telstar, which went on to be a success in its own right, with over a dozen models.

## Early 8-bit Home Consoles (1977-1983)

Home video-game systems became popular during the 1970s and 80s. In the earliest consoles, the computer code for one or more games was hardcoded into microchips using discreet logic, and no additional games could ever be added. By the mid-1970s, video games were found on cartridges. Programs were burned onto ROM chips that were mounted inside plastic cartridge casings that could be plugged into slots on the console. When the cartridges were plugged in, the general-purpose microprocessors in the consoles read the cartridge memory and ran whatever program was stored there. Rather than being confined to a small selection of games included in the box, consumers could now amass libraries of game cartridges.

The Fairchild VES was the world's first cartridge-based video game console. It was released by Fairchild Semiconductor in August 1976. When Atari released their VCS the next year, Fairchild quickly re-named it to the Fairchild Channel F.

In 1977, Atari released its cartridge-based console called the Video Computer System (VCS), later called Atari 2600. Nine games were designed and released for the holiday season. It would quickly become by far the most popular of all the early consoles.

In 1978, Magnavox released its cartridge-based console, the Odyssey 2, in the United States and Canada. Philips Electronics released this same game console as the Videopac G7000 in many European countries. Although it never became as popular as Atari, it managed to sell several million units through 1983.

In 1979, Activision was created by disgruntled former Atari programmers. It was the first third-party developer of video games. Many new developers would follow their lead in succeeding years.

The next major entry was Intellivision, introduced by Mattel in 1980. Though chronologically part of what is called the "8-bit era", the Intellivision had a unique processor with instructions that were 10 bits wide (allowing more instruction variety and potential speed), and registers 16 bits wide. The system, which featured graphics superior to the older Atari 2600, rocketed to popularity.

Unique among home systems of the time was the Vectrex, the only one to feature vector graphics.

1982 saw the introduction of the Colecovision, an even more powerful machine. Its sales also took off, but the presence of three major consoles in the marketplace and a glut of poor quality games began to overcrowd retail shelves and erode consumers' interest in video games. Within a year this overcrowded market would crash.

The popularity of early consoles was strongly influenced by their ports of arcade games. The 2600 was the first with Space Invaders, and the Colecovision had Donkey Kong.

Early cartridges were 2KB ROMs for Atari 2600 and 4K for Intellivision. This upper limit grew steadily from 1978 to 1983, up to 16KB for Atari 2600 and Intellivision, 32KB for Colecovision. Bank switching, a technique that allowed two different parts of the program to use the same memory addresses was required for the larger cartridges to work.

In the game consoles, high RAM prices at the time limited the RAM (memory) capacity of the systems to a tiny amount, often less than a Kilobyte. Although the cartridge size limit grew steadily, the RAM limit was part of the console itself and all games had to work within its constraints.

By 1982 a glut of games from new third-party developers less well-prepared than Activision began to appear, and began to overflow the shelf capacity of toy stores.

In part because of these oversupplies, the video game industry crashed, starting from Christmas of 1982 and stretching through all of 1983.

## The 1980s

In the early 1980s, the computer gaming industry experienced its first major growing pains. Publishing houses appeared, with many honest businesses (and in rare cases such as Electronic Arts, successfully surviving to this day) alongside fly-by-night operations that cheated the games' developers. While some early 80s games were simple clones of existing arcade titles, the relatively low publishing costs for personal computer games allowed for many bold, unique games; a legacy that continues to this day. The primary gaming computers of the 1980s emerged in 1982: the Commodore 64 and ZX Spectrum.

The golden age of arcade games reached its full steam in the 1980s, with many technically innovative and genre-defining games in the first few years of the decade. Defender (1980) established the scrolling shooter and was the first to have events taking place outside the player's view, displayed by a radar view showing a map of the whole playfield. Battlezone (1980) used wireframe vector graphics to create the first true three-dimensional game world. 3D Monster Maze (1981) was the first 3D game for a home computer, while Dungeons of Daggorath (1982) added various weapons and monsters, sophisticated sound effects, and a "heartbeat" health monitor. Pole Position (1982) used sprite-based, pseudo-3D graphics when it pioneered the "rear-view racer format" where the player's view is behind and above the vehicle, looking forward along the road with the horizon in sight. The style would remain in wide use even after true 3D graphics became standard for racing games. Pac-Man (1980) was the first game to achieve widespread popularity in mainstream culture and the first game character to be popular in his own right. Dragon's Lair (1983) was the first laserdisc game, and introduced full-motion video to video games.

With Adventure establishing the genre, the release of Zork in 1980 further popularized text adventure games in home computers and established developer Infocom's dominance in the field. As these early computers often lacked graphical capabilities, text adventures proved successful. When affordable computers started catching up to and surpassing the graphics of consoles in the late 1980s, the games' popularity waned in favor of graphic adventures and other genres. The text adventure would eventually be known as interactive fiction and a small dedicated following has kept the genre going, with new releases being nearly all free.

Also published in 1980 was Roberta Williams' Mystery House, for the Apple II. It was the first graphic adventure on home computers. Graphics consisted entirely of static monochrome drawings, and the interface still used the typed commands of text adventures. It proved very popular at the time, and she and husband Ken went on to found Sierra On-Line, a major producer of adventure games. Mystery House remains largely forgotten today.

In August of 1982, the Commodore 64 was released to the public. It found initial success because it was marketed and priced aggressively. It had a BASIC programming environment and advanced graphic and sound capabilities for its time, similar to the Colecovision console. It would become the most popular home computer of its day in the USA and many other countries and the best-selling single computer model of all time internationally.

At around the same time, the ZX Spectrum was released in the UK and quickly became the most popular home computer in most of Western Europe, and later the Soviet bloc due to the ease with which clones could be produced.

SuperSet Software created Snipes; a text-mode networked computer game in 1983 to test a new PC based computer network and demonstrate its capabilities. Snipes is officially credited as being the original inspiration for Novell Netware. It is believed to be the first network game ever written for a commercial personal computer and is recognised alongside 1974's Maze War (a networked multiplayer maze game for several research machines) and Spasim (a 3D multiplayer space simulation for time shared mainframes) as the precursor to multi-player games such as Doom and Quake.

The true modern adventure game would be born with the Sierra King's Quest series in 1984. It featured color graphics and a third person perspective. An on-screen player-controlled character could be moved behind and in front of objects on a 2D background drawn in perspective, creating the illusion of pseudo-3D space. Commands were still entered via text. Lucasarts would do away with this last vestige feature of text adventures when its 1987 adventure Maniac Mansion built with its SCUMM system allowed a point-and-click interface. Sierra and other game companies quickly followed with their own mouse-driven games.

With Elite in 1984, David Braben and Ian Bell ushered in the age of modern style 3D graphics in the home, bringing a convincing vector world with full 6 degree freedom of movement and thousands of visitable planetary systems into the living room. Initially only available for the BBC Micro and Acorn Electron, the success of this title caused it eventually to be ported to all popular formats, including the Commodore 64, ZX Spectrum, Commodore Amiga, Atari ST and even the Nintendo Entertainment System, although this version only received a European release.

The personal computer became a competitive gaming platform with IBM's PC/AT in 1984. The new 16-color EGA display standard allowed its graphics to approach the quality seen in popular home computers like the Commodore 64. Sound however, was still only the crude bleeps of PC speakers. The primitive 4-color CGA graphics of previous models had limited the PC's appeal to the business segment, since its graphics failed to compete with the C64 or Apple II.

The Apple Macintosh also arrived at this time. It lacked the color capabilities of the earlier Apple II, instead preferring a much higher pixel resolution, but the operating system support for the GUI attracted developers of some interesting games (e.g. Lode Runner) even before color returned in 1987 with the Mac II.

In computer gaming, the later 1980s are primarily the story of the United Kingdom's rise to prominence. The market in the U.K. was well positioned for this task: personal computer users were offered a smooth scale of power versus price, from the ZX Spectrum up to the Amiga, developers and publishers were in close enough proximity to offer each other support, and the NES made much less of an impact than it did in the United States, being outsold by the Master System.

The arrival of the Atari ST and Commodore Amiga in 1985 was the beginning of a new era of 16-bit machines. For many users they were too expensive until later on in the decade, at which point advances in the IBM PC's open platform had caused the IBM PC compatibles to become comparably powerful at a lower cost than their competitors. The VGA standard developed for IBM's new PS/2 line in 1987 gave the PC the potential for 256-color graphics. This was a big jump ahead of most 8-bit home computers but still lagging behind platforms with built-in sound and graphics hardware like the Amiga, causing an odd trend around 1989-91 towards developing to a seemingly inferior machine. Thus, while both the ST and Amiga were host to many technically excellent games, their time of prominence proved to be shorter than that of the 8-bit machines, which saw new ports well into the 80s and even the 90s. AdLib set an early defacto standard for sound cards in 1987, with its card based on the Yamaha YM3812 sound chip. This would last until the introduction of Creative Labs' Sound Blaster in 1989, which took the chip and added new features while remaining compatible with AdLib cards, and creating a new de facto standard. However, many games would still support these and rarer things like the Roland MT-32 and Disney Sound Source into the early 90s. The initial high cost of sound cards meant they would not find widespread use until the 1990s.

Shareware gaming first appeared in the late 1980s, but its big successes came in the 1990s.

## Bulletin Board Systems and Early Online Gaming

Dialup bulletin board systems were popular in the 1980s, and sometimes used for online game playing. The earliest such systems, in the late 1970s and early 1980s, had a crude plain-text interface, but later systems made use of terminal-control codes (the so-called ANSI art, which included the use of IBM-PC-specific characters not actually part of an ANSI standard) to get a pseudo-graphical interface. Some BBSes offered access to various games which were playable through such an interface, ranging from text adventures to gambling games like blackjack (generally played for "points" rather than real money). On multiuser BBSs (where more than one person could be online at once), there were sometimes games allowing the different users to interact with one another; some such games of the fantasy role-playing variety were known as MUDs, for "multi-user dungeons". Today, a popular game in this category is Urban dead.

Commercial online services also arose during this decade, starting with a plain-text interface similar to BBSs (but operated on large mainframe computers permitting larger numbers of users to be online at once), and moving by the end of the decade to fully-graphical environments using software specific to each personal computer platform. Popular text-based services included CompuServe, The Source, and GEnie, while platform-specific graphical services included Quantum Link for the Commodore 64, AppleLink for the Apple II and Macintosh, and PC Link for the IBM PC, all of which were run by the company which eventually became America Online; and a competing service, Prodigy. Interactive games were a feature of these services, though until 1987 they used text-based displays, not graphics.

## Handheld LCD Games

Nintendo's Game & Watch line began in 1980. The success of these LCD handhelds spurred dozens of other game and toy companies to make their own portable games, many being copies of Game & Watch titles or adaptations of popular arcade games. Improving LCD technology meant the new handhelds could be more reliable and consume fewer batteries than LED or VFD games, most only needing watch batteries. They could also be made much smaller than most LED handhelds, even small enough to wear on one's wrist like a watch. Tiger Electronics borrowed this concept of video gaming with cheap, affordable handhelds.

## 8-Bit Era, or 'Post-Crash/Late' 8-Bit Era (1985-1989)

In 1984, the computer gaming market took over from the console market following the crash of that year. Computers offered equal gaming ability and, since their simple design allowed games to take complete command of the hardware after power-on, they were nearly as simple to start playing with as consoles.

In 1985, the North American video game console market was revived with Nintendo's release of its 8-bit console, the Famicom, known in the United States under the name Nintendo Entertainment System (NES). It was bundled with Super Mario Bros. and suddenly became a success. The NES dominated the North American market until the rise of the next generation of consoles in the early 1990s. Other markets were not as heavily dominated, allowing other consoles to find an audience like the PC Engine in Japan and the Sega Master System in Europe, Australia and Brazil (though it was sold in America as well).

In the new consoles, the gamepad took over joysticks, paddles, and keypads as the default game controller included with the system. The gamepad design of an 8 direction D-pad with two or more action buttons became the standard.

The Dragon Quest series made its debut in 1986 with Dragon Quest, and has created a phenomenon in Japanese culture ever since. Also at this time, SquareSoft was struggling and Hironobu Sakaguchi decided to make their final game, titled Final Fantasy (1987); a role-playing game (RPG) modelled after Dragon Quest, and the Final Fantasy series was born as a result. Final Fantasy saved Squaresoft from bankruptcy, and would later go on to become the most successful RPG franchise. At around the same time, the Legend of Zelda series made its debut on the NES with The Legend of Zelda (1986). Hideo Kojima's Metal Gear series also made its debut with the release of Metal Gear (1987) on the MSX2 computer, giving birth to the stealth-based game genre. Metal Gear was ported to the NES shortly after. In 1989, Capcom released Sweet Home (1989) on the NES, which served as a precursor to the survival horror game genre.

In 1988 Nintendo published their first issue of Nintendo Power Magazine.

## The 1990s

If the 1980s were about the rise of the industry, the 1990s were about its maturing into a Hollywood-esque landscape of ever-increasing budgets and increasingly consolidated publishers, with the losers slowly being crushed or absorbed. As this happens, the wide variety of games that existed in the 1980s appears to fade away, with the larger corporations desiring to maximize profitability and lower risk.

With the increasing computing power and decreasing cost of processors like Intel 386, 486, and Motorola 68000, the 1990s saw the rise of 3D graphics, as well as "multimedia" capabilities through sound cards and CD-ROMs.

In the early 1990s, shareware distribution was a popular method of publishing games for smaller developers, including then-fledgling companies such as Apogee (now 3D Realms), Epic Megagames (now Epic Games), and id Software. It gave consumers the chance to try a trial portion of the game, usually restricted to the game's complete first section or "episode", before purchasing the rest of the adventure. Racks of games on single 5 1/4" and later 3.5" floppy disks were common in many stores, often only costing a few dollars each. Since the shareware versions were essentially free, the cost only needed to cover the disk and minimal packaging. As the increasing size of games in the mid-90s made them impractical to fit on floppies, and retail publishers and developers began to earnestly mimic the practice, shareware games were replaced by shorter demos (often only one or two levels), distributed free on CDs with gaming magazines and over the Internet.

Shareware was also the distribution method of choice of early modern first-person shooters (FPS) like Wolfenstein 3D and Doom. Following Doom, the retail publishers and developers began to earnestly mimic the practice of offering demos, which had the effect of reducing shareware's appeal for the rest of the decade. During this time, the increasing computing power of personal computers began to allow rudimentary 3D graphics. 1993's Doom in particular was largely responsible for defining the genre and setting it apart from other first-person perspective games. The term FPS has generally come to refer to games where the player has full control over a (usually humanoid) character and can interact directly with the environment; almost always centering around the act of aiming and shooting with multiple styles of weapons and limited ammunition.

1992 saw the release of real-time strategy (RTS) game Dune II. It was by no means the first in the genre (that being 1983's Stonkers for the ZX Spectrum), but it set the standard game mechanics for later blockbuster RTS games like Warcraft and Command and Conquer. The RTS is characterised by an overhead view, a “mini-map", and the control of both the economic and military aspects of an army. The rivalry between the two styles of RTS play - WarCraft style, which used GUIs accessed once a building was selected, and C&C style, which allowed construction of any unit from within a permanently visible menu - continued into the start of the next millennium.

Alone in the Dark (1992) planted the seeds of what would become known as the survival horror genre. It established the formula that would later flourish on CD-ROM-based consoles, with games like Resident Evil and Silent Hill.

Adventure games continued to evolve, with Sierra's King's Quest series, and LucasFilms'/LucasArts' Monkey Island series bringing graphical interaction and the creation of the concept of "point-and-click" gaming. Myst and its sequels inspired a new style of puzzle-based adventure games. Published in 1993, Myst itself was one of the first computer games to make full use of the new high-capacity CD-ROM storage format. It went on to remain the best-selling game of all time for much of the decade, and was one of the "killer apps" that made CD-ROM drives standard features on PCs. Despite Myst's mainstream success, the increased popularity of action-based and real-time games led adventure games and simulation games, both mainstays of computer games in earlier decades, to begin to fade into obscurity.

It was in the 1990s that Maxis began publishing its successful line of "Sim" games, beginning with SimCity, and continuing with a variety of titles, such as SimEarth, SimCity 2000, SimAnt, SimTower, and the wildly popular day to day life simulator, The Sims in 2000.

In 1996, 3dfx released the Voodoo chipset, leading to the first affordable 3D accelerator cards for personal computers. These devoted 3D rendering daughter cards performed most of computation required for rendering higher-resolution, more-detailed three-dimensional graphics, allowing for more-detailed graphics than would be possible if the CPU were required to handle both game logic and graphical tasks. First-person shooter games (notably Quake) were among the first to take advantage of this new technology. While other games would also make use of it, the FPS would become the chief driving force behind the development of new 3D hardware, as well as the yardstick by which its performance would be measured, usually quantified as the number of frames per second rendered for a particular scene in a particular game.

Several other, less-mainstream, genres were created in this decade. Looking Glass Studios' Thief and its sequel were the first to coin the term "first person sneaker", although it is questionable whether they are the first "first person stealth" games. Turn-based strategy progressed further, with the Heroes of Might and Magic (HOMM) series (from 3DO) luring many main-stream gamers into this complex genre.

The 1990s also saw the beginnings of Internet gaming, with MUDs (Multi-User Dungeons) in the early years. Id Software's 1996 game Quake pioneered play over the Internet in first-person shooters. Internet multiplayer capability became a defacto requirement in almost all FPS games. Other genres also began to offer online play, including RTS games like Microsoft's Age of Empires, Blizzard's WarCraft and StarCraft series, and turn-based games such as Heroes of Might and Magic. MMORPGs (Massively Multiplay Online Roleplaying Games), such as Ultima Online and EverQuest freed users from the limited number of simultaneous players in other games and brought the MUD concept of persistent worlds to graphical multiplayer games. Developments in web browser plugins like Java and Macromedia Flash allowed for simple browser-based games. These are small single player or multiplayer games that can be quickly downloaded and played from within a web browser without installation. Their most popular use is for puzzle games, classic arcade games, and multiplayer card and board games.

Gamers in the 90s began to take their fates into their own hands, with the creation of modifications (or "mods") for popular games. It is generally accepted that the earliest mod was Castle Smurfenstein, for Castle Wolfenstein. Eventually, game designers realised that custom content increased the lifespan of their games, and so began to encourage the creation of mods. Half-Life spawned perhaps the most successful (or, at the very least, one of the most widely played) mods of all time, with a squad-based shooter entitled CounterStrike. Since CounterStrike, many games have encouraged the creation of custom content. Other examples include Unreal Tournament, which allowed players to import 3dsmax scenes to use as character models, and Maxis's The Sims, for which players could create custom objects.

Few new genres have been created since the advent of the FPS and RTS, with the possible exception of the third-person shooter. Games such as Grand Theft Auto III, Splinter Cell, Enter The Matrix and Hitman all use a third-person camera perspective but are otherwise very similar to their first-person counterparts.

## Decline of Arcades

With the 16-bit and 32-bit consoles, home video games began to approach the level of graphics seen in arcade games. By this time, video arcades had earned a reputation for being seedy, unsafe places. An increasing number of players would wait for popular arcade games to be ported to consoles rather than going out. Arcades had a last hurrah in the early 90s with Street Fighter II and the one-on-one fighting game genre it founded. As patronage of arcades declined, many were forced to close down. Classic coin-operated games have become largely the province of dedicated hobbyists. The gap left by the old corner arcades was partly filled by large amusement centres dedicated to providing clean, safe environments and expensive game control systems not available to home users. These are usually based on sports like skiing or cycling, as well as rhythm games like Dance Dance Revolution, which have carved out a large slice of the market. As video games gained in home popularity, the rise of different video game businesses also came about, that employed teams of people to design and market video games and systems. The video game industry was on the rise, names of companies were becoming well known and executives of video game companies could sit back in their lavish business office furniture and watch the markets grow.

## Handhelds Come of Age

In 1989, Nintendo released the Game Boy, the first handheld console since the ill-fated Microvision ten years before. The design team headed by Gumpei Yokoi had also been responsible for the Game & Watch systems. Included with the system was Tetris, a popular puzzle game. Several rival handhelds also made their debut around that time, including the Sega Game Gear and Atari Lynx. Although most other systems were more technologically advanced, they were hampered by higher battery consumption and less third-party developer support. While some of the other systems remained in production until the mid-90s, the Game Boy remained at the top spot in sales throughout its lifespan.

In 1994, Nintendo released the Super Game Boy, an adapter for the Super NES which allowed Game Boy games to be played on the console.

## 16-Bit Era (1989-1994)

The North American market was dominated by the Sega Genesis early on after its debut in 1989, with the Nintendo Super NES proving a strong, roughly equal rival in 1991. The NEC TurboGrafx 16 was the first 16-bit system to be marketed in the region, but did not achieve a large following, partly due to a limited library of English games and effective marketing from Sega.

The intense competition of this time was also a period of not entirely truthful marketing. The Turbographx 16 was billed as the first 16-bit system but the central processor was an 8-bit HuC6280, with only its HuC6260 graphics processor being a true 16-bit chip. Sega used the term Blast Processing to describe the simple fact that its CPU ran at a higher clock speed than the SNES (7.67 MHz vs 3.58 MHz).

In Japan, the PC Engine's (Turbografx 16) 1987 success against the Famicom and CD drive peripheral allowed it to fend off the Mega Drive (Genesis) in 1988, which never really caught on to the same degree as outside Japan. The PC Engine eventually lost out to the Super Famicom, but retained enough of a user base to support new games well into the late 1990s.

CD-ROM drives were first seen in this generation, as add-ons for the PC Engine in 1988 and the Megadrive in 1991. Basic 3D graphics entered the mainstream with flat-shaded polygons enabled by additional processors in game cartridges like Virtua Racing and Starfox.

SNK's Neo-Geo was the most expensive console by a wide margin when it was released in 1990, and would remain so for years. It was also capable of 2D graphics in a quality level years ahead of other consoles. The reason for this was that it contained the same hardware that was found in SNK's arcade games. This was the first time since the home Pong machines that a true-to-the-arcade experience could be had at home.

## 32-Bit / 64-Bit Era (1994 - 1999)

In 1994-1995, Sega released Sega Saturn and Sony made its debut to the video gaming scene with the PlayStation. Both consoles used 32-bit technology, opening the door for 3D games.

After many delays, Nintendo released its 64-bit console, the Nintendo 64 in 1996, selling more than 1.5 million units in only three months. The flagship title, Super Mario 64, became a defining title for 3D platformer games.

PaRappa the Rapper popularized rhythm, or music video games in Japan with its 1996 debut on the PlayStation. Subsequent music and dance games like Beatmania and Dance Dance Revolution became ubiquitous attractions in Japanese arcades. They became known as Bemani games, with the name being derived from Beatmania. While Parappa, DDR, and other games found a cult following when brought to North America, music games would not gain a wide audience in the market until the next decade.

Other milestone games of the era include Rare's Nintendo 64 title GoldenEye 007 (1997), which was critically acclaimed for actually being a good movie-licensed game as well as the first good FPS on a console. The Legend of Zelda: Ocarina of Time (1998), Nintendo's 3D debut for the Legend of Zelda adventure game series, is often regarded as the greatest game of all-time by various critics. The success of Metal Gear Solid (1998) for the PlayStation established stealth-based games as a popular genre.

Nintendo's choice to use cartridges instead of CD-ROMs for the Nintendo 64, unique among the consoles of this period, proved to have negative consequences. In particular, SquareSoft, which had released all previous games in its Final Fantasy series for Nintendo consoles, now turned to the PlayStation. Final Fantasy VII (1997) was a huge success, establishing the popularity of role-playing games in the west and making the PlayStation the primary console for the genre.

By the end of this period, Sony had dethroned Nintendo, with the PlayStation outselling the Nintendo 64. The Saturn was successful in Japan but a failure in North America, leaving Sega outside of the main competition.

# The 2000s

The 2000s (decade) showed innovation on both consoles and PCs, and an increasingly competitive market for portable game systems.

The phenomena of user-created modifications (or "mods") for games - one trend that began during the Wolfenstein 3D and Doom-era - continued into the start of the 21st century. The most famous example is that of Counter-Strike; released in 1999, it is still one of the most popular online first-person shooter, even though it was created as a mod for Half-Life by two independent programmers. Eventually, game designers realized the potential of mods and custom content in general to enhance the value of their games, and so began to encourage its creation. Some examples of this include Unreal Tournament, which allowed players to import 3dsmax scenes to use as character models, and Maxis' The Sims, for which players could create custom objects.

In China, video game consoles were banned in June 2000. This has led to an explosion in the popularity of computer games, especially MMOs. Consoles and the games for them are easily acquired however, as there is a robust grey market importing and distributing them across the country. Another side effect of this law has been rampant video game piracy.

## Sixth Generation Consoles (1998 - 2013)

In the sixth generation of video game consoles, Sega exited the hardware market, Nintendo fell behind, Sony solidified its lead in the industry, and Microsoft developed a gaming console.

The generation opened with the launch of the Dreamcast in 1998. It was the first console to have a built-in modem for Internet support and online play. While it was initially successful, sales and popularity would soon begin to decline with contributing factors being Sega's damaged reputation from the relative failures of the 32X and Saturn, software pirating, and the overwhelming anticipation for the upcoming PlayStation 2. Production for the console would discontinue in most markets by 2002 and would be Sega's final console before it reorganized its business as a third party game provider only, partnering primarily with its old rival Nintendo.

The second release of the generation was Sony's PlayStation 2, which featured DVD-based game discs with 4.7GB capacity, increased processor and graphics capability over its predecessor including progressive-scan component video connections, built-in 4-player connection capability, available Ethernet adapter (which became built-in with the Winter 2004 release of the "slimline" PS2 chassis), and the ability to play DVD movies and audio CDs, eliminating the need for a separate DVD player and making the PS2 a complete home entertainment console.

Nintendo followed a year later with the GameCube (code-named "Dolphin" while in development), its first optical disc-based console, which used 80mm "mini-DVD" discs holding 1.4GB of data each (over 200 times the capacity of the largest N64 cartridge ROM). While it had the component-video capability of its contemporaries, the GameCube suffered in several ways compared to Sony's PS2. Firstly, the PS2's high anticipation and one-year head start gained it player and developer attention before the GCN's release. As a result, the GameCube had less third-party backing and very few third-party exclusives, mostly from Nintendo-faithful studios such as the now-defunct Rare Ltd. and Midway Games, and ironically its old rival Sega, which released several of its Sonic the Hedgehog titles originally planned for Dreamcast. Cross-platform giants like Capcom, Electronic Arts and Activision released most of their GameCube titles on other consoles as well, while other developers like Square Enix continued to release high-demand PS2 exclusives like Final Fantasy X. The GCN's game disc capacity was a third that of the PS2's full-size DVD disks, forcing a few games to be released on multiple discs and most titles to compromise on texture quality and other features of GameCube games, when other platforms had no such limitations on their versions. It had no backwards-compatibility with the now-obsolete cartridges of the N64 (its only cartridge-based adapter allowed playing Game Boy/GBC/GBA games), making the GCN's title count a small fraction of the combined titles for the PlayStation and PS2 that were playable on the fully backward-compatible PS2 console. It was a dedicated game console, with the optical drive being too small to hold a full-size CD or DVD.

Lastly, and most significantly, the GameCube was hindered by a not-undeserved reputation for being a "kid's console", due to its initial launch color scheme (mostly purple, derived from the SNES but with the colors reversed. Nintendo would later release a grey-on-black version), small gamepad design with no neutral color options and a face button layout catering to smaller and less-coordinated hands (though the reversal of the D-pad and the left analog stick positions as compared to the Dual Shock controller of the PlayStation was an advantage to many), and lack of mature-content games which the current market appeared to want. Though T- and M-rated titles including the GCN-exclusive Metroid Prime franchise did exist, the overwhelming majority of GCN games were E-rated and mostly cartoon-style in their art design.

Before the end of 2001, Microsoft Corporation, best known for its Windows operating system and its professional productivity software, entered the console market with the Xbox. Based on Intel's Pentium III CPU, the console used a great deal of PC technology to leverage its internal development, including the ability for developers to write games that leveraged the popular DirectX accelerated-graphics library and other Windows-based APIs, making games for PC easily portable to the Xbox. In order to gain market share and maintain its toehold in the market, Microsoft reportedly sold the Xbox at a significant loss and concentrated on drawing profit from game development and publishing. Shortly after its release in November 2001, Bungie Studio's Halo: Combat Evolved instantly became the driving point of the Xbox's success, and the Halo series would later go on to become one of the most successful console shooters of all time. By the end of the generation, the Xbox had drawn even with the Nintendo GameCube in sales globally, but since nearly all of its sales were in North America, it pushed Nintendo into third place in the American market.

In 2001, Grand Theft Auto III was released, popularizing open world games by using a non-linear style of gameplay. It was very successful both critically and commercially and is considered a huge milestone in gaming. It was also yet another set piece in the debate over video game violence and adult content, with advocacy groups decrying the series' glorification of prostitution, the mafia, and of course violence, including violence against first responders such as police and EMS.

Nintendo still dominated the handheld gaming market in this generation. The Game Boy Advance in 2001 maintained Nintendo's market position with a high-resolution, full-color LCD screen and 16-bit processor allowing ports of SNES games and simpler companions to N64 and GameCube games. Finnish cellphone maker Nokia entered the handheld scene with the N-Gage, but it failed to win a significant following.

Console gaming largely continued the trend established by the PlayStation toward increasingly complex, sophisticated, and adult-oriented gameplay. Game developers continued to cater to the late Gen-X and early Gen-Y gamers that had been their base as pre-teens and tweens in the 1970s and 80s, and were now in their twenties and thirties. Most of the successful sixth-generation console games were rated T and M by the ESRB, including many now-classic gaming franchises such as Halo, Grand Theft Auto and Resident Evil; the latter two of which were notable for both their success and notoriety. Even Nintendo, widely known for its aversion to adult content (with very few exceptions, most notably Conker's Bad Fur Day for the Nintendo 64), began publishing more M-rated games, with Silicon Knights's Eternal Darkness: Sanity's Requiem and Capcom's Resident Evil 4 being prime examples. This trend in "hardcore" console gaming would partially be reversed with the seventh generation of consoles and their focus on motion-based gameplay, leading to more family-friendly titles.

In January 2013, Sony announced that the PlayStation 2 had been discontinued worldwide, ending the sixth generation.

## Seventh Generation Consoles (2004-2010)

The generation opened early for handheld consoles, as Nintendo introduced their Nintendo DS and Sony premiered the PlayStation Portable (PSP) within a month of each other in 2004. While the PSP boasted superior graphics and power, following a trend established since the mid-1980s, Nintendo gambled on a lower-power design but featuring a novel control interface. The DS's two screens, one of which was touch-sensitive, proved extremely popular with consumers, especially young children and middle-aged gamers, who were drawn to the device by Nintendo's Nintendogs and Brain Age series, respectively. While the PSP attracted a significant portion of veteran gamers, the DS allowed Nintendo to continue its dominance in handheld gaming. Nintendo updated their line with the Nintendo DS Lite in 2006, the Nintendo DSi in 2008 (Japan) and 2009 (Americas and Europe), and the Nintendo DSi XL, while Sony updated the PSP in 2007 and again with the smaller PSP Go in 2009. Nokia withdrew their N-Gage platform in 2005 but reintroduced the brand as a game-oriented service for high-end smartphones on April 3, 2008.

In console gaming, Microsoft stepped forward first in November 2005 with the Xbox 360, and Sony followed in 2006 with the PlayStation 3, released in Europe in March 2007. Setting the technology standard for the generation, both featured high-definition graphics over HDMI connections, large hard disk-based secondary storage for saved games and downloaded content, integrated networking, and a companion on-line gameplay and sales platform, with Xbox Live and the PlayStation Network, respectively. Both were formidable systems that were the first to challenge personal computers in power (at launch) while offering a relatively modest price compared to them. While both were more expensive than most of the previous consoles, the Xbox 360 enjoyed a substantial price edge, selling for either $300 or $400 depending on model, while the PS3 launched with models priced at $500 and $600. Coming with Blu-ray Disc and Wi-Fi, the PlayStation 3 was the most expensive game console on the market since Panasonic's version of the 3DO, which retailed for little under $700. The PlayStation 3's high price led to the console being defeated by the Xbox 360 (also resulting in Xbox 360 gaining market leadership until 2008), thus breaking the streak of dominance that the PlayStation brand once had, which was started in 1994 with the success of the original PlayStation. However, the slim model and the PlayStation Move controllers caused a massive recovery for PlayStation 3, and the console would soon outsell Xbox 360 by 2013.

In this generation, Nintendo not only secured its dominance in the handheld video game market, but also successfully regained total dominance on the both the home video game market and the entire video game industry with the release of its home console, the Wii. While the Wii had lower technical specifications than both the Xbox 360 and PlayStation 3, only a modest improvement over the GameCube and the only 7th-gen console not to offer HD graphics, its new motion control was much touted, and its lower price point of around $200–$250 appealed to budget-conscious households. Many gamers, publishers, and analysts initially dismissed the Wii as an underpowered curiosity, but were surprised as the console sold out through the 2006 Christmas season, and remained so through the next 18 months, becoming the fastest selling game console in most of the world's gaming markets. As a result, the Wii became a global success, having outsold the Xbox 360 and relegated PlayStation 3 to third place, thus making the Wii the first Nintendo console to outsell a PlayStation console, and the runaway market leader of the seventh generate of consoles. As of September 2013, the Wii has sold 100.3 million units worldwide and is currently Nintendo's best selling home console. Also, the Wii became the first Nintendo console to have its number of units sold reach 100 million.

The Wii's major strength was its appeal to audiences beyond the base of "hardcore gamers", with its novel motion-sensing, pointer-based controller design allowing players to use the Wii Remote as if it were a golf club, tennis racket, baseball, sword, or steering wheel. The intuitive pointer-based navigation was reminiscent of the familiar PC mouse control, making the console easier for new players to use than a conventional gamepad. The console launched with a variety of first-party titles meant to showcase what the system could do, including the commonly bundled Wii Sports, the party game Wii Play, and The Legend of Zelda: Twilight Princess which received widespread critical acclaim for its art, story and gameplay, including its intuitive sword-and-shield use of the motion-sensing controllers. Third-party support, on the other hand, was slower in coming; game designers, used to the conventional gamepad control sets, had difficulty adapting popular franchises to the heavily motion-based Wii controller, and some didn't bother, preferring instead to concentrate on what they felt to be their core audience on the Xbox 360 and PlayStation 3. Of the top 15 best-selling games for Wii, 12 were developed by Nintendo's in-house EAD groups.

In June 2009, Sony announced that it would release its PSP Go for US$249.99 on October 1 in Europe and North America, and Japan on November 1. The PSP Go was a newer, slimmer version of the PSP, which had the control pad slide from the base, where its screen covers most of the front side.

# The 2010s

The new decade has seen rising interest in the possibility of next generation consoles being developed in keeping with the traditional industry model of a five-year console life cycle. However, in the industry there is believed to be a lack of desire for another race to produce such a console. Reasons for this include the challenge and massive expense of creating consoles that are graphically superior to the current generation, with Sony and Microsoft still looking to recoup development costs on their current consoles and the failure of content creation tools to keep up with the increased demands placed upon the people creating the games.

On June 14, 2010, during E3, Microsoft revealed their new Xbox 360 console referred to as the Xbox 360 S or Slim. Microsoft made the unit smaller and quieter, while also installing a 250GB hard drive and built-in 802.11n WiFi. It started shipping to US stores the same day, not reaching Europe until July 13.

The Onlive cloud-based gaming system would be one of the first cloud gaming systems known in video game history.

## Gaming Without Controllers

On November 4, 2010, Microsoft released Kinect in North America, and later in other parts of the world, as a peripheral for the Xbox 360; it was packaged with the console as well. It uses a sensor and dual-camera device to track the motion of the players themselves. It sold an average of 133,333 units a day for the first 60 days and a total of 8 million units during the same period, earning it the Guinness World Record for the "fastest selling consumer electronics device". Sales passed 10 million units as of March 9, 2011.

## Eighth Generation Consoles (2011–Present)

The Nintendo 3DS is a handheld video game console, revealed at Nintendo's 2010 E3 press conference. Released in Japan in February 2011, it was released worldwide less than a month later. It uses autostereoscopic 3D to produce a 3D effect on-screen.

### PlayStation Vita

On January 27, 2011, the PlayStation Vita (code-named Next Generation Portable, or NGP, during development) was announced. It has a 5-inch OLED multi touch front screen and a rear touch pad, two analog sticks, 3G and WiFi connection, Sixaxis control and 3-axis electronic compass. It was released on December 17 in Japan and released on the 15th (First edition bundle) and on the 22nd February in Europe (3G/ Wifi Vita, release bundle Vita, or the WiFi only Vita), and also in the Middle East, Australia and North America.

### Wii U

The Wii U is a video game console from Nintendo. Billed as the successor to the Wii, it was mentioned in statement released by Nintendo on April 25, 2011, that the company was planning to reveal it during E3 2011 and that playable console units would be present as well. Code-named Project Café, it was officially introduced on June 7, 2011 with its final name, Wii U. The console released in North America on November 18th, and in Europe, Australia and New Zealand on November 30, 2012, officially starting the "eighth generation" of video game consoles. Features of the new console include HD graphics support (on Wii U only), and a controller, the Wii U GamePad, which features a 6.2 inch touch screen built-in that can be used as a second screen providing additional info and interactivity, such as "asymmetric gameplay". The Wii U GamePad allows some games to be played without the need of a TV set, through Off-TV Play. Most peripheral hardware from its predecessor, the Wii, such as the Wii Remote and Wii Nunchuk, Classic Controller and Wii Balance Board work with the new console, as well as the console itself being backward compatible with all Wii and Virtual Console titles. The Wii U discontinues backwards-compatibility support for Nintendo GameCube discs and controllers, which also means that Wii games that support the GameCube's controller will instead require use of an alternate control scheme such as the Classic Controller when playing them on the Wii U. The Wii U also has its own more conventional controller, the Wii U Pro Controller, which resembles an Xbox 360 controller in form and function and is compatible with most Wii U and Virtual Console titles, but not original Wii games. The console is available in two sets. The basic set includes the Wii U console with 8 GB of internal memory, the Wii U GamePad, an AC adapter, an HDMI cable, and the Wii Sensor Bar. The Deluxe set includes all of the items in the basic set but it has 32 GB of internal memory instead of only 8 GB, and is bundled with a GamePad charging cradle, stands for the GamePad and the console, and Nintendo Land. On November 30, 2012, the Wii U was released in Europe, Australia and New Zealand. A sensor bar is not included in the Basic set in Europe, Australia and New Zealand.

### PlayStation 4

The PlayStation 4 (or PS4) is a video game console from Sony Computer Entertainment. Billed as the successor to the PlayStation 3, the PlayStation 4 was officially announced at a press conference on February 20, 2013. The fourth home console in Sony's PlayStation series, it was launched on November 15, 2013 in North America and November 29, 2013 in Europe, and early 2014 in Japan. Moving away from the Cell architecture, the PlayStation 4 is the first in the Sony series to feature compatibility with the x86 architecture, specifically x86-64, which is a widely used platform common in many modern PCs. The idea is to make video game development easier on the next-generation console, attracting a broader range of developers large and small. These changes highlight Sony's effort to improve upon the lessons learned during the development, production and release of the PS3. Other notable hardware features of the PlayStation 4 include 8 GB of GDDR5 RAM memory and a faster Blu-ray drive.

### Xbox One

The Xbox One is a video game console from Microsoft. Billed as the successor to the Xbox 360, the Xbox One was officially announced at a press conference on May 21, 2013. Microsoft had intended to implement strict controls over game resale and DRM controls, but later reversed its decision due to public backlash. It is the third home console in Microsoft's Xbox series and launched on November 22, 2013 in North America, United Kingdom, Spain, Mexico, Italy, Ireland, Germany, France, Canada, Brazil, Austria, New Zealand and Australia. The release was delayed until 2014 in 8 European countries (Belgium, Denmark, Finland, Netherlands, Norway, Russia, Sweden, and Switzerland) due to various localization issues.

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